Resource Roads in British Columbia: Environmental challenges at the site level

November 7–8, 2012
Cranbrook, British Columbia, Canada

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Thanks to our sponsors and volunteers!

This workshop was hosted by the Columbia Mountains Institute of Applied Ecology. The CMI is proud to have worked with these agencies, which contributed financial assistance in support of this event.

The Columbia Mountains Institute gratefully acknowledges the financial support of **Columbia Basin Trust,** a regional corporation created to deliver social, economic, and environmental benefits to the residents of the Columbia Basin. http://www.cbt.org/

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Our presenters and the people who brought posters and displays travelled from various communities in British Columbia and the US Pacific Northwest. We are grateful for your willingness to share your expertise with us, and for the support of your agencies in sending you to our workshop.

We appreciate the willingness of **Ray Warden**, Ktunaxa Nation Council, and **Hon. Wayne Stetski**, Mayor of Cranbrook, for offering a welcome at the start of the workshop.

Special thanks go to our volunteers **Julie Tyrrell, Leigh Anne Isaac, and Ryland Nelson** for their help in keeping the event running smoothly.

We are appreciative of the work of our event organizing committee, and others who contributed expertise as the workshop developed. The members of the organizing committee were:

- **Patrick Daigle,** CMI Director, Chair of organizing committee, and Master of Ceremonies.
- **Martin Carver,** Aqua Environmental Associates
- **Malcolm Gray,** Ministry of Forest, Lands and Natural Resource Operations
- **Peter Jordan,** Ministry of Forest, Lands and Natural Resource Operations
- **Doug Martin,** Ministry of Forest, Lands and Natural Resource Operations
- **Darcy Monchak,** One Sparrow Images
- **Jackie Morris,** Columbia Mountains Institute of Applied Ecology
- **Richard Thompson,** Ministry of Environment
- **Del Williams,** Forest Practices Board

About the Columbia Mountains Institute of Applied Ecology

www.cmiae.org

The Columbia Mountains Institute of Applied Ecology (CMI) is a non-profit society based in Revelstoke, British Columbia. The CMI is known for hosting balanced, science-driven events that bring together managers, researchers, educators, and natural resource practitioners from across southeastern British Columbia. The CMI's website includes conference summaries from all of our events, and other resources.

Workshop description

Within British Columbia, paved and unpaved road length increased by 82% between 1988 and 2005. In 2000, there were over 420,000 road-stream crossings in BC; over the subsequent five years, road-stream crossings increased by about 13,000 per year (BC Ministry of Environment 2007). Estimates of unpaved roads vary from 400,000 to 550,000 km across the province (BC Forest Practice Board 2005). Many more backcountry roads have been built since. The environmental effects of backcountry roads are diverse, and include impacts on aquatic and terrestrial wildlife and habitat, soils, and water. At this event we addressed both the site-level environmental impacts of backcountry roads and management responses.

Eighty people attended our 1.5 day workshop on November 7–8, 2012 at the Rocky Mountain Prestige Inn in Cranbrook. BC. Participants heard 18 speakers, and viewed 7 posters and displays. A networking / social session at the end of the first day was sponsored by DWB Consulting Services.

The summaries of presentations in this document were provided by the speakers. Apart from small edits to create consistency in layout and style, the text appears as submitted by the speakers.

The information presented in this document has not been peer reviewed.

Summaries of presentations

1. The diverse environmental impacts of roads on ecosystems, wildlife, and their habitats

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Resource roads can have a broad range of negative effects on aquatic and terrestrial ecosystems, plant and animal species and their habitats, and other natural resource attributes. This summary is largely based on the references cited below.

On the one hand: The positive effects of roads—mostly it's humans who benefit

To begin with, it is worth noting that there are positive effects of roads. These positive aspects tend to address human needs and wants, e.g., getting people from place-to-place and accessing resources and jobs within resource sectors, as well as homes and communities.

Roads may also benefit some plants and animals. Roads frequently increase edge habitat (which may benefit some plants and animals due to more light and/or altered temperatures) and function as animal migration corridors (e.g., quicker travel with less energy exerted).

On the other hand: The negative social and economic impacts of resource roads

However, roads can have negative social impacts that can create human health and economic hardships. These include: human injuries caused by wildlife–vehicle collisions; insurance claims owing to wildlife–vehicle collisions and road-triggered landslides; economic burdens of managing expanding road networks (e.g., inventories and assessments to inform decisions) and on-the-ground actions (e.g., maintaining surfaces, drainage and stream crossings); garbage dumping and other illegal actions; introduced noxious weeds negatively affecting water quality, ranching, agriculture, and forestry; road-generated fine sediments which are detrimental to commercial species (e.g., salmon) or that necessitate domestic water treatment; and road surfaces that cannot produce ecological services for humans (e.g., growing timber, sequestering carbon, and filtering water).

To generalize, roads are built for human reasons, by a variety of players, usually with resource development interests. In British Columbia, we carry on building roads as development continues, so we must persist in creating ways to avoid and mitigate the negative effects of roads.

The broad array of environmental impacts of resource roads

Within the research and management literature, road-related impacts have been considered (or sliced and diced) in various ways.

1. Road-related impacts have temporal dimensions. For example, impacts may occur only during road construction or from the subsequent presence, use, and maintenance of the road and its verges. Negative effects may continue when roads are abandoned. On the other hand, when roads are abandoned, some positive effects could occur (e.g., habitat for primary-succession plants, access for hikers).

2. Road impacts include biotic components (e.g., species, ecosystems) and abiotic components (e.g., hydrology, soils, topography, and geomorphology).

3. The environmental effects of roads include spatial dimensions. For example, effects can be local (along a road segment, the site level) or extensive (related to a large road network, the landscape level). In addition to the direct loss of habitat and ecosystems caused by the road footprint, another spatial aspect is the "road-effect zone", which may extend some distance from the road itself, such that the "effective width" can be many times the actual road width. For example, road-generated sediments can affect watercourses and aquatic habitat far downstream. The spatial effects of roads vary because of the diversity of species' habitat requirements and ecosystem characteristics.

4. Road effects may be direct (e.g., vehicle – animal collisions; ecosystem reductions) or indirect (e.g., more frequent encounters with people can displace large mammals).

Becoming more specific, road-related impacts include:

- Wildlife road-kills and injuries (e.g., mammals, birds, reptiles, amphibians, and turtles);
- Road-kill carrion may become attractants to carrion-feeding wildlife and result in additional wildlife collisions;

- Increased animal mortality (and injuries) because of expanded opportunities for hunting, angling, trapping, and poaching, as well as resource management actions;
- Loss of species, habitat, and native vegetation (within the road corridor), particularly when roads are in riparian areas;
- Changed or fragmented habitat caused by road-associated development tenures (e.g., logging, mining, energy, commercial recreation, domestic grazing…);
- Altered habitat caused by increased human-induced fire ignition, fire suppression and exclusion actions, fencing, fire-wood gathering, public recreation, garbage dumping, and urban expansion;
- Reduced habitat effectiveness and suitability, due to stepped up human disturbance of wildlife (e.g., from traffic movement, lights, pollution, and noise, as well as human presence);
- Increased wildlife harassment and human–wildlife conflicts;
- Modified wildlife behaviour:
    - Changes to animal movement (daily, annual)
    - Home range shifts
    - Reduced body mass, reproduction, or survival
    - Habituation to human presence
    - Road avoidance or escape responses
    - Altered predator–prey relations along artificial "hard-edge" habitat created by roads (e.g., nest predation by cowbirds, jays, and ravens)
    - Increased access for predators that travel on roads (e.g., wolves preying on previously isolated caribou).
- Amplified number and extent of landslides resulting in displaced and altered soils that may change:
    - Soil layers
    - Soil pH
    - Soil permeability
    - Water retention
    - Light levels
    - Soil temperature
    - Vegetative community composition and structure
    - Biomass productivity (e.g., plant growth)
- Reconfigured landforms resulting in changed hydrologic regimes, including:
    - Disrupted water table
    - Interrupted groundwater flow
    - Elevated water temperature, due to reduced riparian vegetation
    - Changes in timing of runoff and intensity of high and low flows

  - Increased sediment and nutrient delivery to streams, lakes and wetlands with adverse effects on aquatic organisms
  - Drained natural wetlands
  - Unintentional artificial wetlands
  - Disrupted large organic debris input to streams, which can affect channel morphology
  - Restricted or stream channels
  - Altered water velocity
  - Disrupted streambed materials
  - Reduced number, size, and depth of stream pools, diminishing habitat for aquatic organisms and fish.
- Disturbed aquatic systems and habitats:
  - Restricted fish passage, eliminating or reducing up-stream migration and access to spawning sites, thereby fragmenting fish habitat
  - Introduced non-native fish; some people use road access to intentionally stock streams and lakes with non-native fish and thus disrupt native aquatic systems.
- Reduced streamside vegetation where roads are located in riparian areas;
- An increased number and extent of invasive alien plants and animals that establish along the colonization corridors provided by roads;
- Expanded unmanaged recreation, which may include unauthorized snowmobiling and All Terrain Vehicle use, and possibly result in negative impacts on wildlife and degradation of soils and riparian and wetland areas;
- Stepped up spread of insects (e.g., truck transport of beetle-infested logs) and disease (e.g., potential pathogen transfers among domestic stock and wildlife);
- More fuel emissions and dust into the air-shed;
- Increased contaminant discharges may permeate soils, water, plants, and animals, and disrupt species composition or cause mortality. These emissions include oil, gasoline, metals, other chemicals, and road de-icing salt (which may attract animals that may be killed in vehicle collisions).

In closure, there is growing concern about the cumulative effects of multiple road-related impacts, especially when the impacts are combined with multiple alterations that occur with the ensuing resource developments that accompany road establishment.

Avoiding and mitigating road-related impacts on the environment

However, importantly, there are approaches for avoiding or mitigating negative road effects. Management recommendations for addressing road-related impacts fall into a few categories:

- Strategic ‘big picture’ approaches;
- Structured inventory, assessment, planning, and informed decision-making;
- Organizing and undertaking on-the-ground mitigation techniques; and
- Conducting effectiveness monitoring and research to identify sound ways of mitigating road impacts.

Within this workshop summary, other authors describe approaches for avoiding or mitigating road impacts.

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2. *Impact of roads on Canada's deforestation estimates: A British Columbia perspective*

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The Deforestation Monitoring Group of the Canadian Forest Service tracks deforestation in Canada using a combination of Landsat and other satellite and aerial imagery, records, and expert judgment. Mapping is done on a national basis using a sampling approach. We provide official estimates and reliable information to policymakers, land managers and the public, on the quantity, trends, and driving forces of deforestation. The public can see the sampling deforestation data and submit feedback on the public input website via http://www.nfis.org. The data are also used in the Carbon Budget Model of the Canadian Forest Service (CBM-CFS3), as a component in the compilation of the annual national carbon budget estimates for forests. These estimates of greenhouse gas (GHG) and deforestation areas are included in the annual National Inventory Report submitted to the United Nations Framework Convention on Climate Change.

The conversion of deforested area to estimates of carbon and other GHG emissions is conducted using the CBM-CFS3 by both the CFS Carbon Accounting Team and, for BC, the Competitiveness and Innovation Branch of the Ministry of Forests, Lands and Natural Resource Operations. The CBM-CFS3 is an empirical model of forest carbon dynamics, built on more than 20 years of CFS science, and allows forest managers to assess the carbon implications of forest management (i.e. increase sinks and reduce sources). To date the model has been downloaded for use by over 1000 people in 54 countries (through http://carbon.cfs.nrcan.gc.ca).

Deforestation is defined as the direct human-induced permanent conversion of forested land to non-forested land. To qualify as forest under the definition, land must have a 25% minimum crown closure at maturity and have tree cover reaching a minimum 5m height at maturity. The minimum forest/deforestation event area is one hectare, and linear events must have a minimum width of 20m from tree base to tree base, with length enough to bring the area to one hectare. Note that under the definition, neither harvest cuts nor skid roads are considered deforestation.

Where a change in land cover is visible between two dates of imagery, and the change is interpreted as being due to deforestation, the event is mapped and added to a GIS database. Landsat imagery is used to identify potential deforestation and often verified using additional data as available, such as high-resolution imagery, aerial photography, Google Earth, records data, and ancillary GIS databases. Winter Landsat imagery is often used to confirm the presence of forest prior to change.

Deforestation mapping is conducted on a sampling basis, so estimates are taken from a detailed sampling grid up to a national level. Areas sampled in Canada and within British Columbia, from a single sampling cell (normally 3.5 x 3.5 km), to the network of sample cells on the vertices of a 10 km sampling grid, to the boundaries of a Landsat image scene, to the national-level deforestation stratification units (areas of supposed consistent deforestation activity), up to the national reconciliation units (RUs), of which 60 cover Canada. Data from these are rolled up to the 18 national reporting zones.

The core output from the process is a database of deforestation estimates that can be sliced in different ways:

- spatial (stratification unit to reporting zone), or “Where did the events occur?”
- temporal (time periods to annually, 1970–2010), or “When did deforestation occur?”. Mapped time periods are 1975–1990, 1990–2000, 2000–2008 and 2008–2012.
- categorical (78 land-use classes to 11 reporting (industrial) classes), or “What is the new land use class?)

Note that the measurements are made in detail to allow for later flexibility through aggregation of classes.

The interpretation process assigns “post-classes” to each interpreted deforestation event. These are also given “post-class modifiers” to provide detail that allows for aggregation of deforestation estimates for specific needs and industries. Roads are mapped by use as highways, forestry, oil and gas, hydro, and mining roads, and are further divided into main, secondary, and tertiary. (Note: only those tertiary roads 20m or wider are included in deforestation estimates.) In order to determine carbon impacts, roads are considered either “forestry” or “transportation”, but the classes can be aggregated differently for specific industries. Note that 12 of the total 11,350 deforestation events mapped in the British Columbia sample are due to forestry-related landslides.

For British Columbia roads, we separate out the oil and gas from the transportation category to give areas of deforestation by resource roads and non-resource roads. The resource roads category for BC includes main and secondary forestry and oil and gas roads. The non-resource roads found include main and secondary other roads. (Note that there are no hydro roads in the deforestation sample for British Columbia.) The total road area in BC developed on forested land 1975–2008 is 52 kha, where 86% are resource roads. Out of all deforestation attributed to resource roads in Canada, British Columbia accounts for 30%, a steadily declining trend from 38% in the 1970s and 1980s, to 20% in the period 2000–2008. The development of non-resource roads in British Columbia accounts for 14% of Canada’s total, a declining trend of 18% in 1970s and 1980s to 8% over 2000–2008.

CBM-CFS3 accounts for the GHG emissions associated with disturbances from harvest, fire, and decomposition over time. When a road is cut through a forest, the carbon is affected as follows:

- 85% of merchantable carbon goes to the forest product sector;
- Some standing dead trees are harvested;
- Uprooting and soil overturning;
- For the remaining woody residue:
    - Forestry: 60% of the area burned and 40% left to decay
    - Transportation: 20% of the area is burned and 80% is left to decay.

It is of interest to the group to determine whether this has changed in current road building practice. To this end we are seeking input from experts in the industry.

Road building activities and methods have an impact on emissions, i.e., in terms of burn *vs*. decay of residual piles. Direct emissions are assumed to be instant emissions of harvested wood products and fire emissions. Residual emissions are the release of carbon from decomposition over time (20 years for deforestation). British Columbia estimates for 1990–2011 are given in the table below.

GHG Emissions	Direct	Residual	Total
Burn Rate (*tCO_2e/ha*)	503	260	763
Decay Rate (*tCO_2e/ha*)	370	398	768
BC 1990–2011 (*$MtCO_2e$*)	11.7	8.6	20.3

In the past various sources have been investigated for use as forest road data: the Ministry of Forests' annual records, which deal only with roads financed by the province; the TFL annual reports, which can be missing from headquarters' archives and may not be consistently reported; and the GIS forest inventory, for which road estimates are unreliably based on a change between two maps. These approaches have both pros and cons. Currently the deforestation estimates use mapping, and where high-resolution imagery is available road widths can be measured.

Mapping for the next round of British Columbia deforestation estimates has started already, with a 2008–2012 examination of British Columbia municipalities (including sub-hectare events) in collaboration with and financed by the province. The CFS is now planning for mapping the remainder of Canada for the same time period.

Local validation of existing mapping is important to the accuracy of the database. In BC, for example, regional agrologists from the Ministry of Agriculture and Lands provided local knowledge and expert opinion on agriculture-related deforestation events using simple Google Earth tools. A CFS innovation project by Dave Hill, "Public Input for Forest Monitoring", expands on this method to include input from the public (available via http://www.nfis.org).

The CFS Deforestation Monitoring Group is always looking for better ways to estimate deforestation. Mapping of roads is difficult and time consuming, and in some regions of Canada it accounts for 90% of the mapping effort. As a group, we are open to suggestions for data sources and help with this effort (e.g., good records or mapping data). We would also like to improve the representation of carbon transfers associated with road building in CBM-CFS3 to refine GHG emission estimates, with help from resource roads experts. It is desirable to get deforestation into the lexicon of the provincial government, so that new roads built will include records of corridor width, and amount of deforestation and volume, as standard components of road reporting in the future.

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3. Impacts of increased road use associated with major project development on listed and other wildlife species in southern British Columbia

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The Waneta Expansion Project is a major project currently under construction near the confluence of the Pend d'Oreille and Columbia Rivers in southeastern British Columbia. Construction was initiated in 2011, the project will take four years to build, and it will involve significant increases in truck, vehicle, and heavy equipment traffic to the area. This area supports high levels of biodiversity, with over 200 vertebrate species confirmed during pre-project surveys. Federal or provincial species at risk (SAR) confirmed include ≥15 vertebrates. An impact assessment predicted that increased road use would result in elevated roadkill mortality as well as localized displacement of wildlife and SAR. Mitigation options implemented to minimize road use mortality included:

1. Promoting worker awareness of risks to SAR using signage at key sites, mandatory worker awareness training, and periodic updates to work crews on roadkill sites and rates;
2. Implementing a speed limit reduction at known aggregation sites of listed herptiles, with a flag person present at peak times;
3. Re-routing animals to safer crossing locations using regularly maintained drift fencing;
4. Conducting long term roadkill monitoring (4 years pre- and 4 years during construction) to quantify impacts and refine mitigation, as needed; and,
5. Developing site-specific mitigation where unacceptable roadkill impacts are occurring.

Few projects have measured increased road use effects over a long time frame on a range of taxa. This ongoing study was designed to:

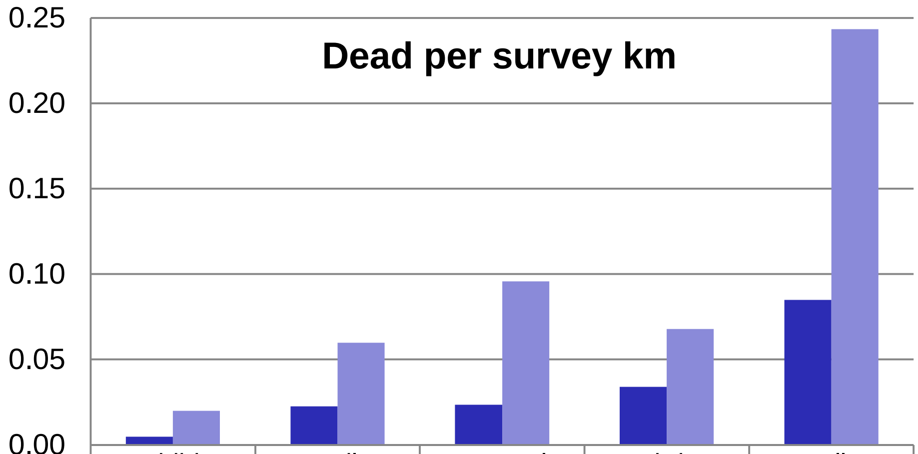
1. Obtain baseline estimates of road use and roadkill by all wildlife guilds, with special emphasis on species at risk;
2. Measure changes to roadkill mortality and road use with construction; and,
3. Evaluate whether mitigation implemented is effective, and develop additional site-specific measures as needed.

Methods

Project area roads (estimated 40 km route; mainly paved) were surveyed on 14 days per season (May 1–October 15). Surveys were conducted by mountain bike and GPS locations of all dead and live wildlife species on or within striking distance of roads (≤2 m height) were recorded. Time spent, kilometres travelled, and numbers of moving vehicles along each segment of the route were recorded. Traffic rates were later calculated by segment, and roadkill mortality rates (baseline and during construction) were calculated per survey hour and per survey kilometre. All roadkill and live detections were mapped to identify potential problem sites for mitigation purposes. Estimates of seasonal roadkill (May 1–October 15) by wildlife guild were generated from mortality rates during surveys, based on a number of assumptions.

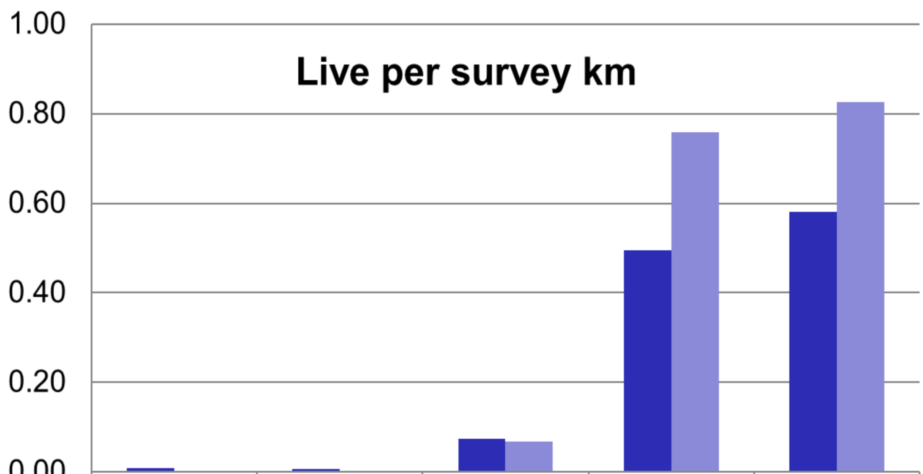
Results

A total of approximately 275 hours were spent surveying during pre-construction (2006–2009) and active construction (2011) years. A total of 253 vertebrates (of 57 different species) were detected dead on project roads, compared with 1,585 live vertebrates (of 83 different species) using the using the roadways. At least seven different listed species were detected dead on roads: Barn Swallow, Common Nighthawk, racer, rubber boa, Townsend's big-eared bat, and western toad.



	Amphibians	Reptiles	Mammals	Birds	All
pre	0.00	0.02	0.02	0.03	0.08
act	0.02	0.06	0.10	0.07	0.24

Figure 1a.



	Amphibians	Reptiles	Mammals	Birds	All
pre	0.01	0.00	0.07	0.49	0.58
act	0.00	0.00	0.07	0.76	0.83

Figure 1b.

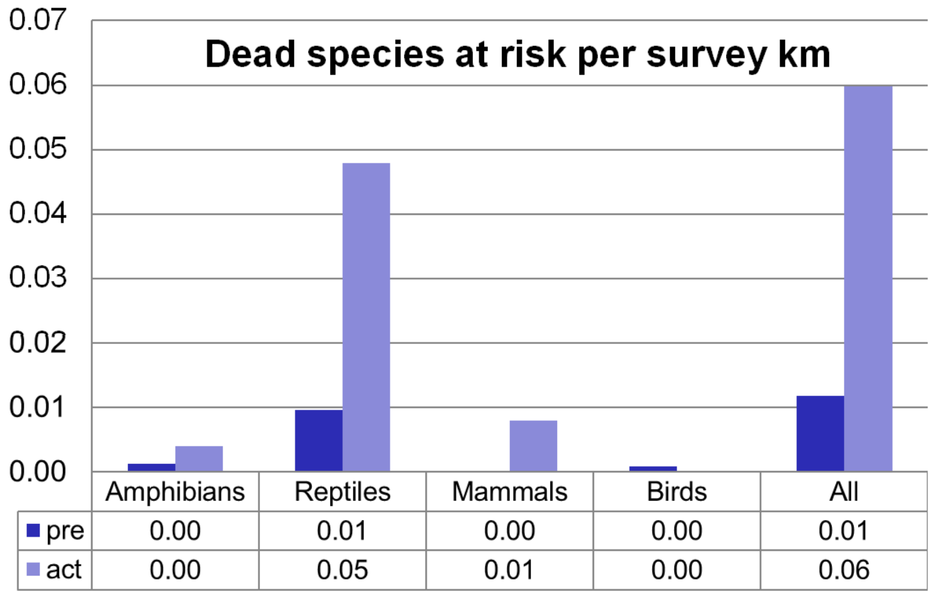


Figure 1c.

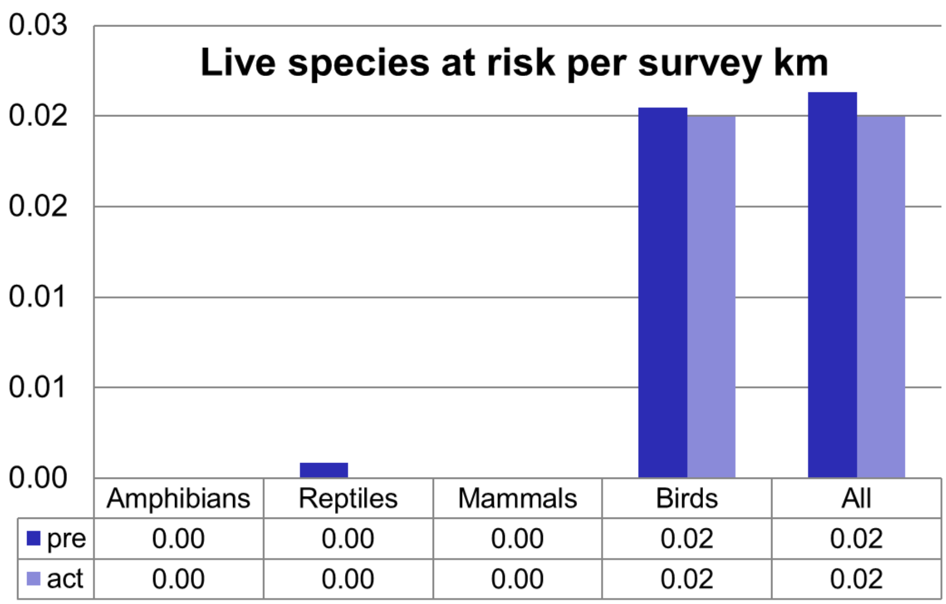
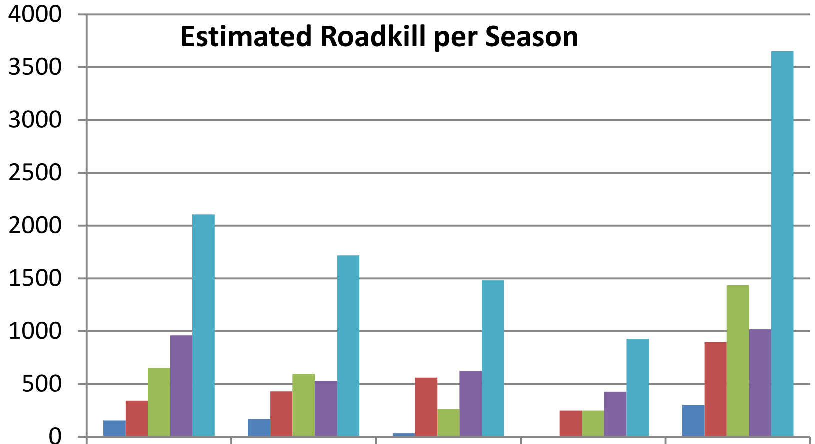


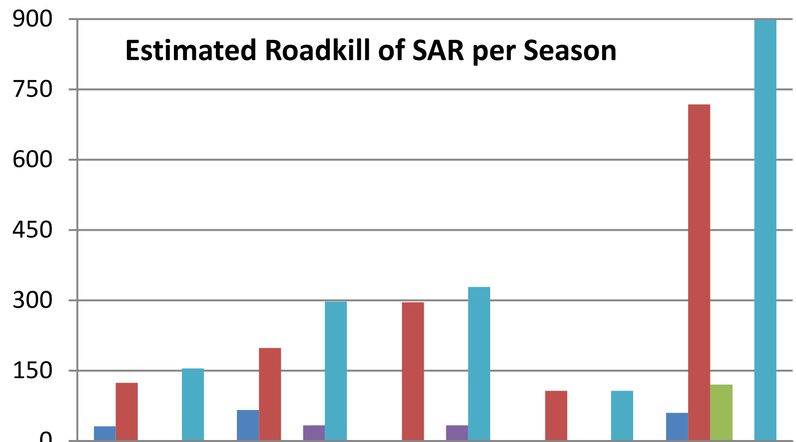
Figure 1d.

Figure 1 (a-d) above. Comparison of average detection rates (per survey km) of dead and live wildlife (a-b) and species at risk (c-d) during pre- versus active construction years. Data are shown by vertebrate wildlife guild and for all guilds pooled. With construction, roadkill rates increased 3-fold and 6-fold for wildlife and SAR, respectively, whereas those for live wildlife/SAR changed little or increased (in the case of birds being flushed off roads more frequently).



	2006	2007	2008	2009	2011
Amphibians	155	165	33	0	299
Reptiles	340	429	559	249	897
Mammals	650	595	263	249	1436
Birds	959	529	625	427	1017
Total	2103	1718	1479	925	3649

Figure 2a.



	2006	2007	2008	2009	2011
Amphibians	31	66	0	0	60
Reptiles	124	198	296	107	718
Mammals	0	0	0	0	120
Birds	0	33	33	0	0
Total	155	297	329	107	897

Figure 2b.

Figure 2 (a-b) above. Estimated seasonal (May 1–October 15) roadkill of wildlife and SAR projected from monitoring findings from 2006 to 2011.

Compared with pre-construction, road-killed vertebrates detected per kilometre surveyed increased 3-fold on average during construction, with increases consistent across all guilds (Figure 1a). There was an average 6-fold increase in dead SAR during construction (Figure 1c), however detections of live wildlife and SAR changed little or actually increased (in the case of birds being flushed off roads more frequently; Figures 1b and d). Projecting over a season, an estimated 3,649 roadkills would have been expected on 40 km of road during 2011 (Figure 2a). Of these, approximately 897 would have been SAR (Figure 2b), with reptiles disproportionately affected.

This monitoring initiative addresses only the spring and summer seasons, and focuses only on diurnal species. It does not address roadkill scavenged prior to being tallied; hence actual roadkill rates are expected to be much higher. Based on results to date, there is a strong positive relationship between increased project area road use (which doubled on average during construction) and elevated numbers of roadkill (Figure 3). All roadkill occurrences were mapped, but the widely dispersed pattern observed (without obvious roadkill "hotspots") makes it difficult to pinpoint specific areas for effective mitigation, so this adverse impact appears to some extent unavoidable. Given the magnitude of roadkill numbers detected, the impacts of road use on biodiversity and in particular to SAR need to be given greater attention during road and other project developments, in roaded areas with high biodiversity, and in areas where significant increases in road use are expected.

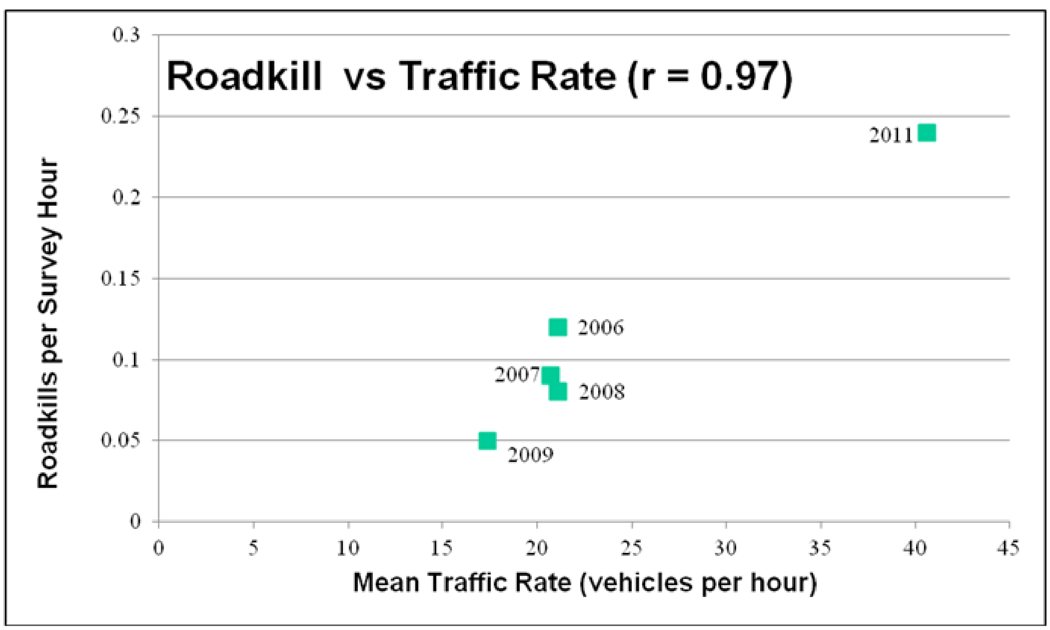


Figure 3. *Mean traffic rate versus roadkills (per survey hour).*

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4. BC Natural Resource Road Act: The state of play today

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The goal of the *Natural Resource Road Act* project is to create a single, streamlined, modernized approach to the management and administration of resource roads in British Columbia. Don Gosnell spoke about the progress of this project to date. The *Natural Resource Road Act* project is now into its second phase: the analysis of the policy issues that emerged from phase one. This analysis will guide the drafting of the legislation when the project reaches that stage.

For updates and information about the *Natural Resource Road Act* project, visit http://www.for.gov.bc.ca/mof/nrra/

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5. Landslides caused by forest roads in British Columbia: Recent trends in landslide occurrence in the West Arm – Lower Kootenay River area

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In the Columbia Mountains of southeastern British Columbia, forest roads are the most significant cause of landslides. A research study conducted 1997–2002 examined approximately 1,200 landslides in study areas totalling 7,000 km^2 of forested terrain. About 2/3 of the landslides were development-related, and of these, about 80% were caused by forest roads. Forest development was found to result in a 4 to 9 times increase in landslide occurrence over the natural rate. Terrain class (genetic material), presence of natural landslides, presence of gullies, and slope were significant factors in explaining landslide density.

More recent landslides were examined in a study area centred on Nelson, in the Lower Kootenay River – West Arm of Kootenay Lake area, which has an abundance of community and domestic watersheds, and a dense rural population in areas subject to potential landslide risk. Several landslides in this area provide examples of road fill failures, drainage diversions by roads, and the effect of clearcuts on increasing snowmelt runoff. Some landslides have a significant impact on water quality in domestic watersheds, which may persist for several years; other landslides have no such impact, even though they entered streams. This may depend on whether or not the stream is at peak flow at the time, how confined the channel is at the point of entry, and whether or not the slide progresses down the channel as a debris flow.

Road drainage continues to be the most significant factor in development-related landslides. Road fill failures continue to occur, mainly on old roads, but they are becoming less common, since most newer roads on steep terrain are constructed to higher engineering standards than previously.

Many recent landslides, although they are caused by road drainage, are considered to be “no-fault” in that there were no substandard practices involved. There is always an unavoidable risk of landslides on roads built in steep or potentially unstable terrain, regardless of careful engineering, because of the inevitable interception and concentration of subsurface flow by roads.

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6. *Inventory and modeling the hydro-geomorphic impacts of forest roads on the Middle Fork of the Payette River, Idaho*

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Forest roads have been shown to cause damage to aquatic resources in many environments. High quality road inventory data can provide an economical way to efficiently address the environmental risks created by roads. The Geomorphic Road Analysis and Inventory Package (GRAIP), can be applied for about $250 per mile, and is relatively simple for field crews to implement and for a hydrologist to analyze. GRAIP combines a detailed field inventory with GIS modeling tools to analyze the impacts that forest roads have on watershed resources. The model predicts fine sediment production and delivery, hydrologic integration of the roads and stream, gully, and landslide risks, and stream channel diversions. This data can free up scarce road maintenance dollars and improve effectiveness by specifically targeting treatments towards areas in the road system that maximize the benefits to the watershed.

The road-related risks to the Middle Fork of the Payette (MFP) watershed were captured by a detailed inventory and modeling effort conducted by the US Forest Service with support from the Environmental Protection Agency. The total amount of fine sediment from mapped roads delivered to the MFP River and its tributaries was modeled to be 1,691Mg/yr, or 20% of total production on the roads. The average GRAIP predicted sediment delivery rate from roads in the study area was 2 Mg/km^2

(5.5 ton/mi^2) although the values for sub-watershed range from zero to 5.3 Mg/km^2 (0–15.0 ton/mi^2). The average sediment delivery was modeled to be 10% of the natural background stream sediment mass observed locally, with a range from zero to 22%. Road-stream hydrologic connectivity was observed to be 163 km (101 mi) or 17% of all road length surveyed. Much of the road impact was focused on a small fraction of the landscape. We found that 90% of the sediment delivery occurs from 10% of the road length and is routed to streams through 7% of the drainage features.

Introduction

Roads can have a variety of impacts on managed watersheds that include sediment delivery, gully and landslide initiation, stream channel diversion, and changes to the timing of small storm hydrographs. Roads can also impact wood recruitment to streams and affect the aquatic and terrestrial habitat. Some of these impacts can be observed directly while other effects play out infrequently in time and space, particularly following large weather events.

The United States Forest Service manages a land base of 780,000 km^2 and administers over 603,000 km of forest roads. Much of this road system was constructed over 30 years ago when timber harvest was more extensive and under a different road engineering paradigm. This results in the present challenge to the US Forest Service of managing an extensive and aging road system using limited resources.

In order to begin to understand the hydrologic and geomorphic impacts of forest roads on watersheds, we developed a road inventory and modeling system called *The Geomorphic Road Analysis and Inventory Package* (GRAIP). The output of this system allows managers to better understand the various types of road-related risk that exist in their watersheds and provides the basis for managing and prioritizing restoration work to address these risks.

GRAIP is used to inventory and model the risk profile of each of the road segments and drain point features included in the study. The GRAIP system consists of a detailed, field-based road inventory protocol combined with a suite of Geographic Information System (GIS) models. The inventory is used to systematically describe the hydrology and condition of a road system with Global Positioning System (GPS) technology and automated data forms (Black et al. 2012). The GIS applications couple field data with terrain analysis tools to analyze road-stream hydrologic connectivity, fine sediment production and delivery, downstream sediment accumulation, stream sediment input, shallow landslide risk potential with and without road drainage, gully initiation risk, and the potential for and consequences of stream crossing failures (Cissel et al. 2012). Detailed information about the performance and condition of the road drainage infrastructure is also supplied.

The study area

The MFP River is a tributary to the Snake River located 80 km north of Boise, Idaho. The main stem of the MFP is listed under the Clean Water Act as impaired by sediment and temperature. The basin is composed of late Cretaceous granodiorites of the Idaho Batholith. The 12 sub-watersheds cover an area of 877 km^2. The watershed is in the snow zone between 900 and 2,650 m in elevation and receives an average annual precipitation of between 50 cm/year and 150 cm/year depending on the elevation. The dominant forest cover is ponderosa pine at the lower elevation and sub-alpine fir at the upper elevation. Much of the basin is managed timber land with 85% public ownership. Three survey crews inventoried all of the roads on public land but not all private roads; 938 km of road and 17,203 drain points (of which 14,016 were active) were documented over portions of three field seasons.

Road–stream hydrologic connectivity

Roads can intercept shallow groundwater and convert it to surface runoff, resulting in local hydrological impacts when that water is discharged directly to channels (Wemple et al. 1996). Additional runoff is also produced from the compacted road surface. Basin-scale studies in the Oregon Cascades suggest that a high degree of integration between the road drainage system and the channel network can increase peak flows (Jones and Grant 1996).

The hydrologically connected portion of the road system is calculated in GRAIP using field observations of connection at each drain point and a road segment flow routing system. The flow path below each drain point is followed until evidence of overland flow ceases or the flow path reaches a channel. In the MFP, 163 km or 17% of the total road length was hydrologically connected to the channel (Table 1). There was substantial variability in the connectivity within the 12 sub-watersheds; from 0% to 44% were hydrologically connected. This is in part due to the large difference in the length and locations of road within the sub-watersheds. Much of the road is located in the southwestern portion of the study area where many stream side roads were built in a steep dissected landscape. In the northeastern portion of the study area, little timber harvest and road development has occurred and fewer stream side roads exist. Thirty four percent of the road is associated with diffuse drainage, which is most common on outsloped roads. These roads delivered very little sediment (2% of the total). Ditch relief culverts drained 19% of the road length and were associated with 34% of the total sediment delivery.

Fine sediment production and delivery

Fine sediment production at a drain point (*E*) is estimated with a base erosion rate and the properties of two flow paths along the road (Luce and Black 1999, Cissel et al. 2012, Prasad 2007), as shown below.

$E = B \times L \times S \times V \times R$

B is the base erosion rate (kg/m)
L is the road length (m) contributing to the drain point
S is the slope of the road contributing to the drain point (m/m)
V is the vegetation cover factor for the flow path
R is the road surfacing factor.

Sediment production on 938 km of road surface was associated with 14,016 active drainpoints and totaled 8,388 Mg/yr. Of these, 11,881 drain points delivered water and sediment back to the hillslope and did not have evidence of surface flow path connection to an active channel. Total sediment delivery from the 2,135 hydrologically connected points was 1,691 Mg/yr. Twenty percent of the material eroded from the road surface and ditch was predicted to deliver to the channel.

Table 1. *GRAIP modeled sediment production, sediment delivery and observed hydrologic connection by drain point type for the MFP, Idaho.*

Drain Point Type	Count	Sediment Production (Mg/yr)	Sediment Delivery (Mg/yr)	% Drain Point Delivery	% of Total Production	% of Total Delivery	Total Road length (m)	% Length	Connected Road length (m)	% connected length
Broad Based Dip	2,086	2,132	219	10%	25%	13%	155,603	17%	16,604	11%
Diffuse Drain	4,546	790	28	4%	9%	2%	314,942	34%	4,913	2%
Ditch Relief Culvert	1,869	1,509	570	38%	18%	34%	177,804	19%	64,958	37%
Lead Off Ditch	125	84	21	24%	1%	1%	9,070	1%	3,116	34%
Non-Engineered	1,712	1,358	254	19%	16%	15%	95,831	10%	19,975	21%
Stream Crossing	369	282	282	100%	3%	17%	34,884	4%	34,884	100%
Sump	127	104	-	0%	1%	0%	9,782	1%	-	0%
Water Bar	3,182	2,127	318	15%	25%	19%	140,483	15%	18,320	13%
All Drains	**14,016**	**8,388**	**1,691**	**20%**	**100%**	**100%**	**938,398**	**100%**	**162,771**	**17%**

The sediment delivery from all drain points was ranked by magnitude to examine the cumulative sediment delivery (Figure 1). Seven percent of all drain points, (967 points) deliver 90% of the sediment, and 2% deliver 50% of sediment at 276 points. This finding that a few drain points and roads are causing the majority of the sediment delivery allows managers to target restoration treatments at the largest sediment sources first. This Pareto relationship has been found in all of the watersheds where we investigated road sediment delivery patterns.

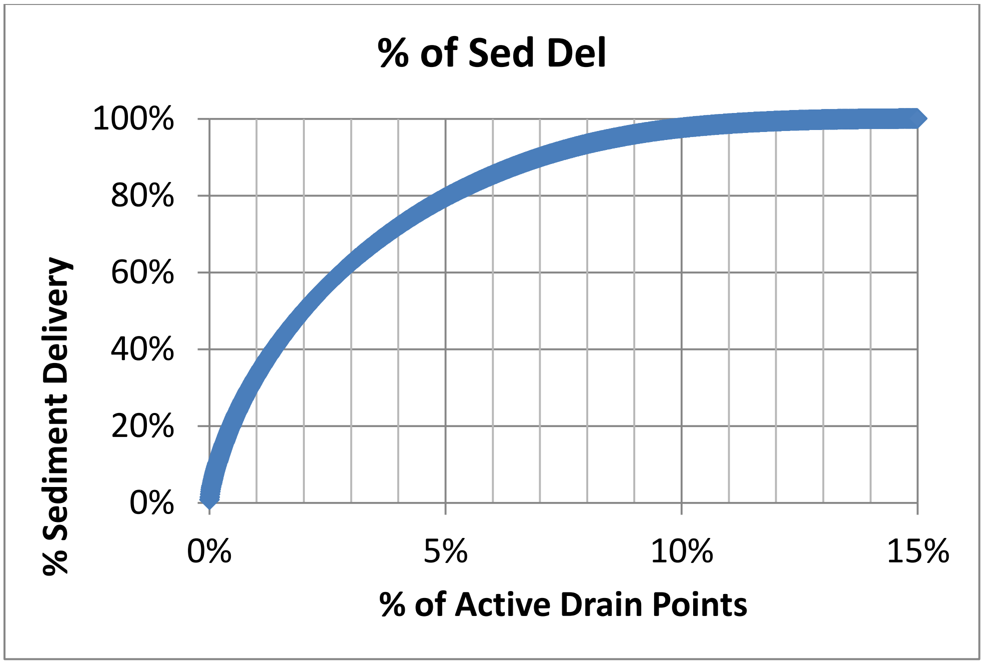

Figure 1. *The fraction of the 14,016 active drainage locations ranked as a cumulative function of their sediment delivery.*

Once we have an accurate map of sediment delivery it is relatively easy to target the top delivering road segments for treatment: 450 Mg of sediment was modeled to deliver at the top 100 drain points, representing 27% of total delivery.

Figure 2 illustrates the pattern of sediment delivery found in the MFP. The main system roads were built along streams and have relatively high sediment delivery. Seventeen of the 100 highest sediment delivery drainpoints are shown here in Anderson Creek accounting for 79 Mg/yr of sediment delivery.

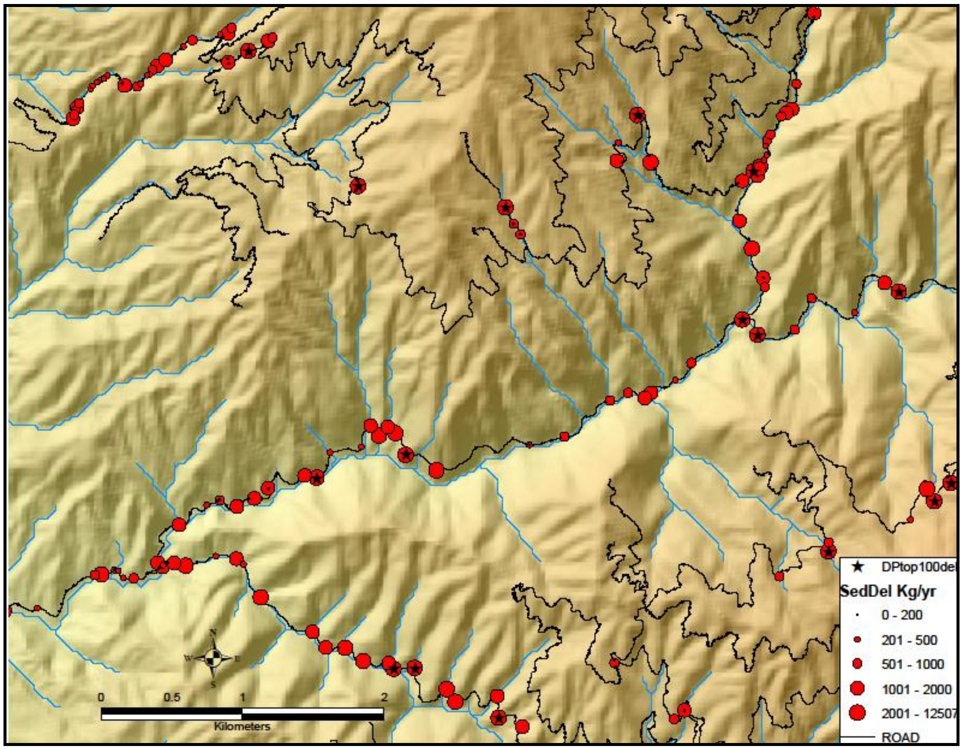

Figure 2. *Sediment delivery from drain points in Anderson Creek. The red circles are scaled to illustrate sediment delivery. Black stars indicate the location of the top 100 sediment delivery points in the MFP watershed.*

We examined the relationship between sediment delivery and several landscape metrics and found that distance to stream, hillslope position, and local ground slope had the best relationship. Seventy-three percent of the total sediment delivery from drains occurs within 100 m of the channel. Drainage locations that were less than 30 meters from the channel had a probability of stream connection of 60% while locations that were in excess of 300 m from the channel had a probability of about 5%. Hillslope position and local ground slope were also closely related to probability of sediment delivery. The highest probability of stream connection occurs on the lower third of the hillslope where local slope was less than 20%.

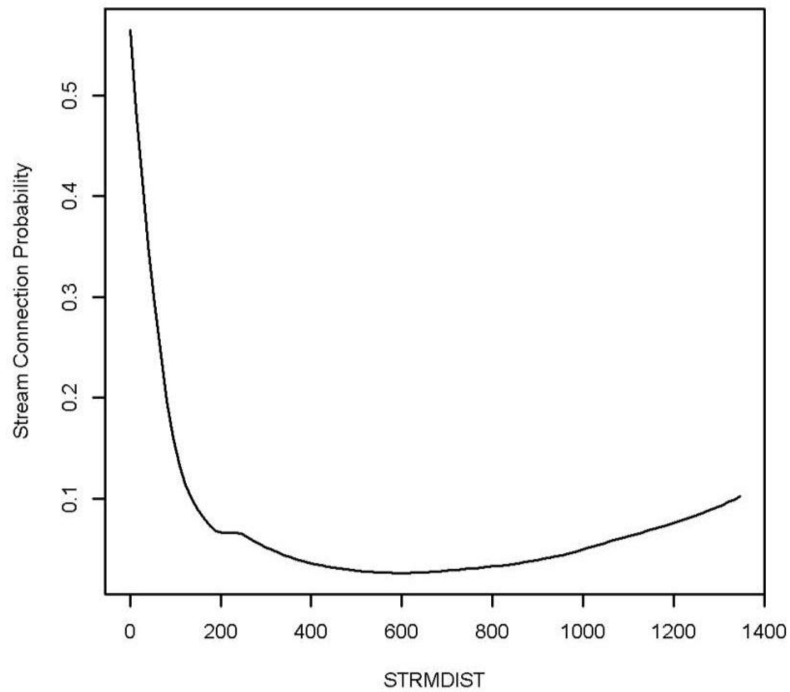

Figure 3. *Local fit to the drain point data showing the probability of stream connection as a function of distance to stream in meters.*

Road surface derived fine sediment enters the stream network below connected drain points. Road-related sediment accumulates in streams and is routed through the network. GRAIP calculates two measures of sediment accumulation for each stream segment. The first measure, sediment accumulation (Figure 4), is the mass of road-related sediment that passes through each stream segment per year. The second measure, specific sediment accumulation, is the mass of road-related sediment normalized by the contributing area. In this metric, area is used as a proxy for discharge, allowing us to compare the sediment impacts to channel segments with differing contributing areas.

Road-related sediment at the mouth of the MFP totaled 1,691 Mg/yr or 1.9 Mg/km^2/yr. Specific sediment accumulation in highly impacted channel segments is as high as 6.5 Mg/km^2/yr. Three sub-watersheds (Anderson, Scriver and Plye) have sediment accumulation above 5 Mg/km^2/yr. Previous work on unmanaged watersheds in Silver Creek measured an annual average erosion rate of 20 Mg/km^2. The most heavily impacted sub-watersheds have road sediment delivery that is 25% above this undisturbed rate, and short channel segments may exceed this.

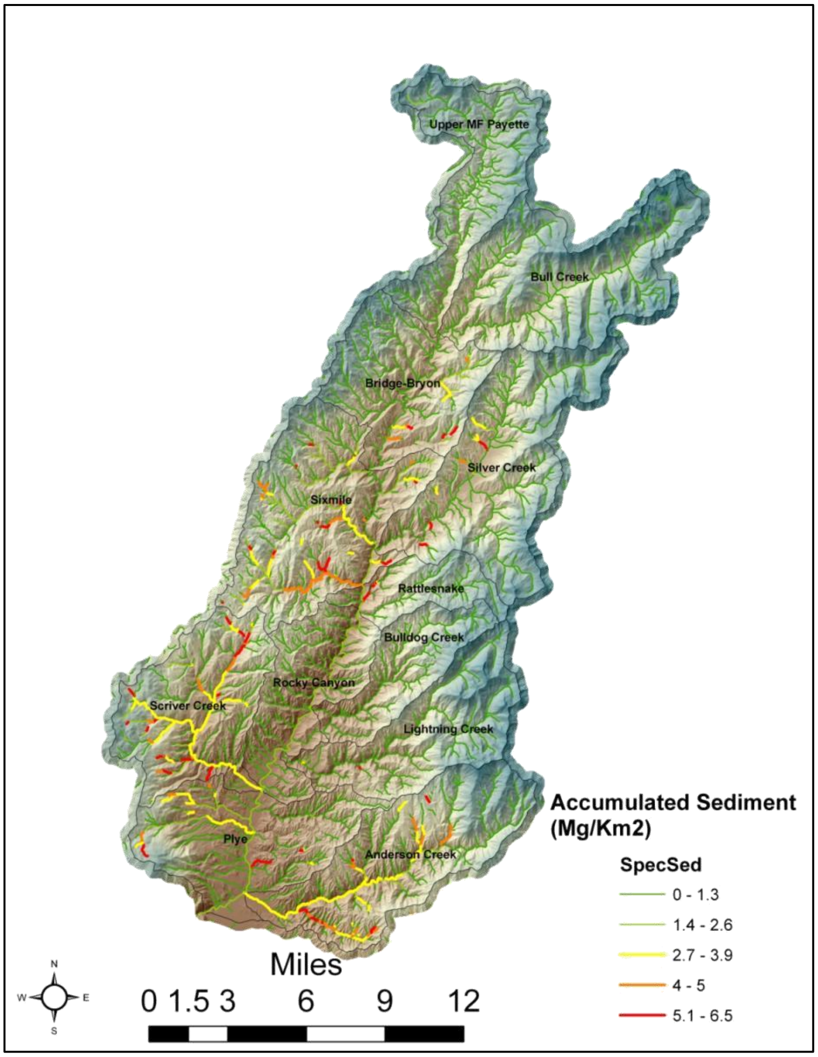

Figure 4. *Sediment accumulation per unit area in stream segments.*

Drain points

Not all road drainage systems are equal. Figure 1 shows total sediment production and sediment delivery grouped by drain point type. Overall, 20% of all the erosion from the road is delivered to the stream. Half of the total sediment is produced on roads drained with water bars and broad-based dips. These two drain points combined deliver only 32% of the sediment that they receive. Stream crossings receive 3% of the sediment produced but deliver 17% of the total. Likewise, ditch relief culverts deliver sediment at almost twice their proportional share from a sediment production or road length basis.

We can also use this data to assess the effectiveness of our best management practices (BMPs). We examined which drain types were likely to deliver the sediment that was routed to them. Stream crossings were most likely to deliver followed by ditch relief culverts, lead off ditches, and non-engineered drains. Diffuse drainage (outsloped roads) and broad-based dips were least likely to deliver.
Another way of looking at our BMP effectiveness is to examine the condition of the drain points. If a drainpoint has more than .14 m^3 (5 ft^3) of erosion or other specific failure types, it is classified as a problem that warrants a follow up. For example, pipes that are significantly rusted, or have greater than 20% occlusion are considered problems. Overall problems were observed at 10% of drains, and 5% had excessive fill erosion. Ditch relief culverts and sumps had the highest failure rate.

In addition to contributing fine sediment to streams through surface erosion, stream crossings may fail catastrophically when blocked and deliver large sediment pulses to stream channels. Stream crossing failure risks were assessed using the Stream Blocking Index (SBI) (Flanagan et al. 1998). The SBI characterizes the risk of plugging by woody debris by calculating the ratio of the culvert diameter to the upstream channel width and the skew angle between the channel and the pipe inlet. Forty-eight of 369 non-bridge stream crossings were considered at high risk of blocking by SBI, and the fill volume at risk above these pipes was about 4,000 m^3.

A second, and perhaps greater, consequence of concern at compromised stream crossings is the diversion of stream flow onto road surfaces or ditches that allow drainage on to unchannelled hillslopes. Once a stream crossing becomes occluded and begins to act as a dam, failure can occur in several ways. If the road grade dips into and rises out of the crossing, the failure is likely to be limited to a localized overtopping of the stream crossing. However, if the road grades away from the stream crossing in one or more directions, the flow may be diverted down the road and ditch and onto adjacent hillslopes, where it can cause gullying and/or landslide (Furniss et al. 1997, Best et al. 1995). In these situations, large volumes of sediment far exceeding those at the crossing can be at risk. Pipe overtopping or flow diversion down the road was recorded at 17 stream crossings.

A total of 199 gullies were mapped and their volumes measured. Gullies occurred at 187 drain points. Most of these gullies occurred below ditch relief culverts and non-engineered features. The volumes were converted to a mass of 24,435 Mg or 490 Mg/yr assuming an average life of 50 years for the road.

To investigate the risk of gully initiation we calibrated the Erosion Sensitivity Index (ESI), based on the length of the road drainage and square of the hillslope below the drain location. The average probability of a gully occurring below a drain location was about 1%. However, when the ESI value exceeded 30 the gully risk rose to about 6%.

We investigated the potential cost savings available from having the detailed GRAIP road inventory information that allows a precise targeting of sediment delivery problems. We used the Scriver Creek integrated restoration plan to help us look at the planned restoration expenditures. The plan for work in one of the sub-watersheds of the MFP calls for 1.2 million dollars in road -based watershed improvement work over a number of years. We used this as a typical case for a large integrated restoration project.

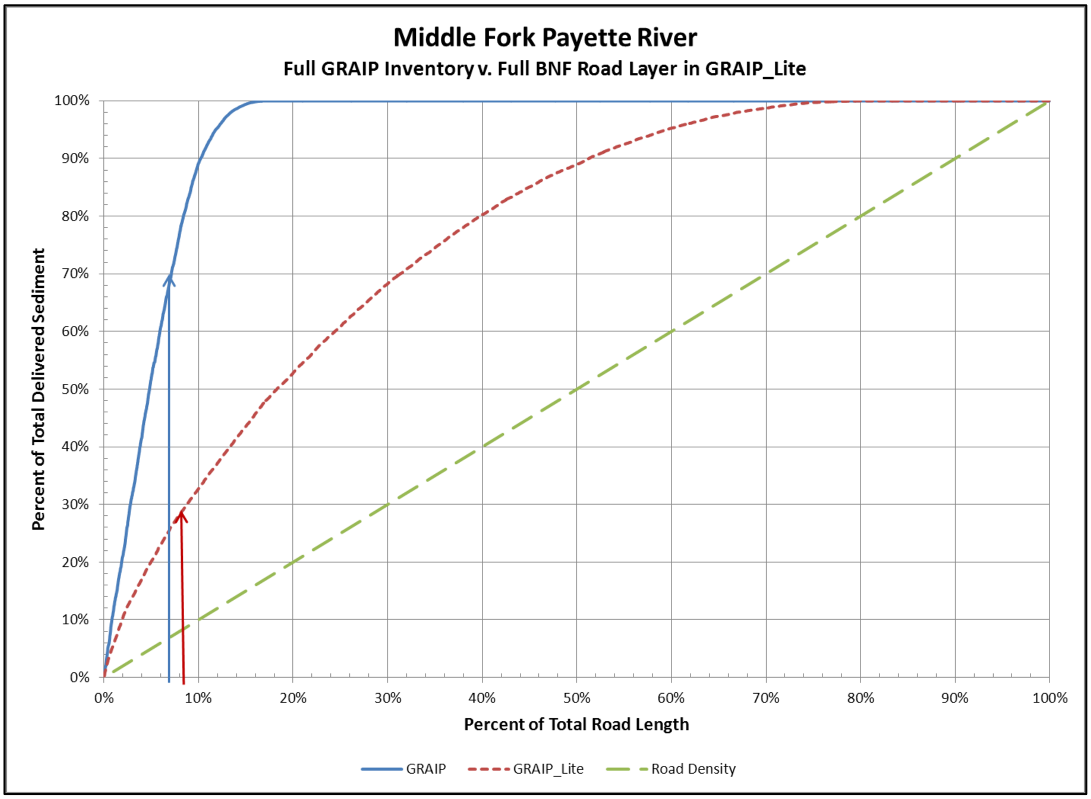

***Figure 5**. This figure shows percentage of sediment delivery as a function of cumulative road length for the MFP. The blue line shows the relationship observed with the GRAIP inventory and model. The red dashed line illustrates general relationship found from GIS analysis of the road lines, stream lines and the digital elevation model without local information about sediment delivery at specific drainage locations. The green line shows the relationship between sediment delivery and road length when no data are available, often known as the road density approach.*

First consider the case where we have the detailed inventory dataset. The GRAIP inventory cost was about $135,000, leaving $1,065,000 for treatments. The figure of $25,000/mile was used as an average value for road decommissioning and aggressive restoration treatment. This would support 43 miles of road treatment. Using the blue GRAIP prioritization curve (Figure 5), we would achieve a 71% reduction in sediment delivery from this amount of work, assuming complete elimination of sediment delivery. To simulate the standard approach that does not have a detailed inventory to predict sediment delivery, we used the road line data and the digital elevation model to predict sediment production and the slope position to predict sediment delivery (Figure 5, red line). There was no inventory cost so 48 miles of road was available for treatment. However the efficiency of treating a mile of road was degraded significantly due to a lack of local stream connection data, so roads were not treated in the optimal order. This case resulted in a 29% reduction in sediment delivery versus a 71% reduction for the GRAIP scenario.

Conclusions

The road related risks to the MFP watershed were captured by a detailed inventory and modeling effort conducted by the US Forest Service. Road sediment delivery below drains, gullying below drains, and flow diversions at stream crossings were the mechanisms most likely to result in water quality degradation. Seventeen percent of the road length was able to deliver water and 1,691 Mg of sediment per year to the fluvial system. GRAIP can aid prioritization and improve the efficiency of restoration work by narrowing the focus to the places that really matter in the watershed, for a variety of processes.

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7. Restoration of resource roads

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Traditional road reclamation treatments have generally failed to meet expectations for biodiversity and sustainability. Uniform stands of seeded agronomic grasses and legumes can remain successionally stagnant for decades making forest recovery difficult and severely limiting biodiversity. The failure to re-establish natural successional trajectories on many traditionally reclaimed areas results in degraded ecological conditions that invite invasion by weedy species resulting in weed infested reclaimed areas. Restoration treatments based on the use of natural processes that have been addressing natural disturbances for millions of years can be very effective. Natural successional processes provide answers to species selection and sequencing questions while natural nutrient cycling processes can suggest soil development solutions. Natural erosion control processes can be applied to bare soils to address erosion issues. Understanding the factors that prevent or limit natural recovery can also be important to determine solutions. Compaction, steep slopes, and excessive erosion are abiotic factors that can prevent recovery while competition and herbivory are common biotic factors that may limit recovery. This paper presents a new model for treatment of drastically disturbed road sites based on the application of these natural processes and the filters (constraints) that limit these processes. Examples are drawn from the author's experience of over 30 years of reclaiming drastically disturbed sites.

Introduction

Reclamation is a critical part of industrial development. Without effective reclamation, social license is lost and the promises made by industry and the permitting part of the government mean nothing. Poor reclamation represents a debt that the creators of the disturbance owe society and the ecosystem (Atwood 2008).

Unfortunately most traditional reclamation treatments have failed to achieve the reclamation objectives that were established when the permits were granted. Hyper-abundant ungulates do not equal productive wildlife habitat but rather an unbalanced system that reduces overall biodiversity (Martin *et al.* 2011). Roads that are to be restored must have a capability that is equal to or better than the land capability that existed on the site prior to the disturbance. The established vegetation cover must be self-sustaining. Although these requirements have been part of the statutory code for many years, the ecological implications of these requirements have not been part of the reclamation lexicon. Failure to address the ecological short-comings of traditional reclamation has led to a loss of societal acceptance of reclamation as a tool for mitigating forest industry disturbances. Weakened or overly prescriptive legal requirements have contributed to this loss. Improperly restored roads, landings, and other disturbances result in a loss of productive capacity in our forests. Regaining societal acceptance will require a significant shift in reclamation treatments.

Restoration is defined by the Society for Ecological Restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SERI 2004). Although reclamation and restoration have traditionally been seen as two distinct activities (Burton 1991), effective reclamation can be considered to be restoration using the concepts of novel ecosystems (Hobbs et al. 2006). By looking at the treatment of forest sites as a restoration challenge, the lost social acceptance can be regained. Treatments that are applied to restore degraded or destroyed sites can be used instead of traditional reclamation treatments with significantly improved outcomes.

This paper is organized to provide a synopsis of how disturbed sites can be effectively restored. The model for restoration that is presented here is based on natural recovery systems. Natural recovery processes have been restoring naturally disturbed sites since the advent of vegetation on the earth over 400 million years ago. Evolutionary processes have honed these recovery systems so that now bare ground in temperate regions does not stay bare for long or if it does, it is because of some other factor (filter) that is preventing recovery. Therefore the first step in restoring a disturbed site is to determine what, if anything is preventing the natural recovery of the site. Polster (2011) identified eight common abiotic filters and six biotic filters that prevent recovery. Understanding how natural systems address these constraints to recovery allows development of restoration treatments that make use of the natural processes, often significantly reducing the cost of conducting restoration.

By definition, drastically disturbed sites are considerably different than immediately adjacent undisturbed sites. Reference to adjacent sites will be of little use in developing restoration strategies for the disturbed site. Soils may be lost or totally changed. Physical features of the substrate may bear little resemblance to the adjacent natural soils. Vegetation is generally lacking or may be composed of weedy, undesirable species. Ecological processes such as nutrient cycling or carbon sequestration may be lacking. Looking to the adjacent ecosystems as a reference for the reclaimed ecosystems may be inappropriate and may result in the incorporation of unsuitable treatments on the disturbed site. Understanding the successional context of the site to be restored allows natural analogues to be investigated and used as models for the establishment of effective treatments.

Filters to recovery

Polster (2011) listed eight abiotic (non-living) filters to recovery:

1. Steep slopes
2. Adverse soil texture (too fine or too coarse)
3. Nutrient status
4. Adverse chemical properties
5. Soil temperature extremes
6. Compacted substrates
7. Adverse micro-climatic conditions
8. Excessive erosion.

Six biotic (living) filters are listed by Polster (2011):

1. Herbivory
2. Competition
3. Phytotoxic exudates
4. Propagule availability
5. Facilitation (of one species to the exclusion of another)
6. Species interactions.

Many of these filters operate in concert to prevent the establishment and growth of vegetation. For instance, compacted substrates may prevent establishing plants from reaching nutrients and moisture, thus these sites also appear to be nutrient and moisture limiting. Similarly a dense, competitive cover of seeded grasses and legumes may foster establishment of hyper-abundant ungulate populations that limit the establishment and growth of woody species that in turn reduce populations of song birds and other species (Martin et al. 2011). Green (1982) identified the problems of small mammals associated with dense grass and legume covers. Trophic cascades (Falk et al. 2006) such as this can have far-reaching consequences for biodiversity and resilience (Holling 1973).

Just as the filters that prevent recovery often act together, the natural solutions to these filters may solve more than one problem. For instance, when trees are blown over in a forest they can turn up large root wads and create open areas that are colonized by pioneering species. This natural process maintains these species in the ecosystem so they are available to address other disturbances in the forests (Straker 1996). In addition, the up-turned soils bring the less mobile nutrients (e.g., P and K and various micro-nutrients) to the surface where they can be accessed by the roots of the pioneering species. The mounds of fresh soil associated with the root wads are located next to the holes from which the root wad came, creating topographic heterogeneity (Larkin et al. 2008). Topographic heterogeneity provides conditions that promote species diversity thus the simple process of trees blowing over in the forest ensures the maintenance of diversity in the forest as well as providing successional and nutrient diversity. The following section looks at natural processes that can be applied to solve common filters preventing recovery.

Natural processes to address filters

The following sections describe how natural processes overcome the common filters listed above. The use of these natural processes to address the filters associated with anthropogenicly disturbed sites is presented with the filter(s) they address.

Abiotic filters

1. *Steep slopes*

Angle of repose slopes will not sustain a vegetation cover due to continual sloughing (Polster and Bell 1980). In the absence of material coming from cliffs above a natural talus slope (colluvial slope) this raveling and sloughing will eventually result in a reduced slope angle that will support a vegetation cover. In some cases colluvial slopes are species rich as the freshly available nutrients and the continual deposition of material allow a diversity of species to establish and grow (Polster 1977). Although such sloughing and raveling will eventually allow vegetation to establish, this may take many millennia. Re-sloping road cuts and fills has been used to address the problem of over-steepened slopes (Atkins et al. 2001). In addition to reducing the slope angle on cut and fill slopes, re-sloping allows the fine textured materials that collect at the top of the slope to be pushed over the coarser materials found further down the slope, addressing, in part the issue of coarse textured materials (see below).

2. Adverse soil texture

Plants need fine textured soil materials for growth. Fine textured materials hold moisture and nutrients allowing plant roots to extract these materials for growth. Soils that have high clay content may dry and crack, and may tightly bind moisture, making it unavailable to plants. Coarse rock that will not support vegetation will weather over time to produce finer textured materials that can support plants. Excessively fine soils such as the clays found in old lake beds or ancient marine environments will be slowly colonized by plants that will add organic matter, which will eventually ameliorate the adverse conditions of the fine soils. Coarse textured substrates are common on many larger road fills. As noted above, re-sloping the fills can be used to spread fine textured soil-like materials over coarse rock thus allowing vegetation to be established. Where large coarse rock fragments exist, organic matter will slowly collect in the interstitial spaces between the rocks. This material will eventually support vegetation (Polster and Bell 1980). In a restoration context, a soil bioengineering technique known as pocket planting (Polster 1997) can be used to assist pockets of vegetation to become established that will eventually spread to fill between the pockets.

3. Nutrient status

Most drastically disturbed sites lack basic plant nutrients. Natural processes provide essential plant nutrients such as nitrogen through nitrogen fixing species. Spawning salmon return to their home waterways bringing marine derived nutrients to coastal forest ecosystems. Weathering of rock provides other, less mobile nutrients (P and K). When trees are blown over in a forest they turn up the soil, renewing these nutrients. Creation of topographic heterogeneity (Larkin et al 2008) mimics these natural processes. Traditionally fertilizers and bio-solids have been used to supply plant nutrients, but these sources favour the growth of non-native agronomic grasses and legumes which have been found to constrain recovery (Polster 2011). Native pioneering species can grow in low nutrient situations and will create conditions where natural processes can provide the needed nutrients for the vegetation that establishes (Walker and del Moral 2003).

4. Adverse chemical properties

Acid rock drainage, salinity, sodic soils, or soils contaminated with metals or hydrocarbons can severely limit plant growth. Although there are some native species (e.g., Tufted-hair grass, *Deschampsia cespitosa*) that are tolerant of high metals levels

(Cox and Hutchison 1980), most plants are excluded where excessive metals are present. Natural sites with toxic metals levels are colonized by species that are tolerant that in turn provide organic matter that eventually chelates the metals, allowing other plants to grow. Salinity naturally moves down the soil column where it does not impact plants. Some natural areas where salts accumulate due to low rainfall and high evaporation rates remain un-vegetated. Typically adverse chemical properties are dealt with by covering the offending materials with sufficient material to allow plant growth without influence of the adverse material. Specific cover designs that will be effective for millennia are needed but are relatively uncommon.

5. *Soil temperature extremes*

Dark coaly shale on south facing slopes can become lethally hot to plants in the summer sun. Similarly, in northern areas, permafrost can create conditions that are too cold for plants to grow. Natural systems bury dark materials under a litter of organic matter while layers of organic matter (active layer) insulate permafrost from growing plants. Making sites rough and loose (Polster 2011) or topographically heterogeneous creates warm and cool slopes and wet and dry conditions, overcoming soil temperature extremes.

6. *Compacted substrates*

Naturally compacted substrates weather until there is sufficient material that is not compacted to allow plant growth. Making road surfaces and other compacted sites rough and loose can be used to de-compact sites. Simple ripping is insufficient to eliminate compaction on road surfaces where logging trucks have been running.

7. *Adverse micro-climatic conditions*

Frost pockets, hot dry knobs and other sites where the micro-climatic conditions limit plant growth may occur. Naturally these sites are vegetated by tolerant vegetation. Making sites rough and loose can ameliorate adverse micro-climatic conditions by creating warm slopes as well as cool slopes.

8. *Excessive erosion*

Erosion is a problem with anthropogenicly disturbed sites. Although natural landslides may inject large quantities of sediment into aquatic systems, they also provide sediments that are important for various natural processes such as fish spawning. There are a variety of natural processes that serve to reduce the potential for erosion. Up to 30% of the rain that falls on a natural forest is caught in the canopy and re-evaporated. Funnel shaped plants such as Swordferns *(Polystichum munitum)* channel rainfall into the groundwater system. Leaves (deciduous and coniferous) that are deposited on the ground protect the soil surface from raindrop erosion and promote infiltration. Making sites rough and loose and promptly establishing pioneering woody species can protect the site from erosion and promote recovery. There are a variety of simple soil bioengineering treatments (e.g., live silt fencing) that can be used to control erosion.

Biotic filters

1. Herbivory

Excessive herbivory can occur where predators have been reduced or where large stands of seeded grasses and legumes promote population explosions. The dense thatch of seeded grasses and legumes can shelter small mammals from predation, allowing these animals to destroy woody species. Natural systems such as burned areas where pioneering species (willows and poplars) might be expected to dominate and attract large herbivores (moose, elk and deer) are often covered by an accumulation of coarse woody debris that prevents easy access by ungulates. Scattering woody debris or building temporary fences can reduce the impacts of excessive herbivory.

2. Competition

Competition is a complex topic (Falk et al. 2006). A species that might be competitive with one species might facilitate another (Temperton et al. 2004). Typically one species is more efficient at using resources than another. For instance, alfalfa tends to be able to extract moisture from the soil more effectively than most woody species so will create a competitive barrier to establishment of those woody species. Seeded grasses and legumes can create a dense competitive cover that prevents establishment of woody species (Polster 2010).

3. Phytotoxic exudates

Some invasive species are successful because they produce chemicals that prevent the establishment of other species. Knapweed and Scotch broom are two examples of such plants. These plants can create successionally stagnant conditions (Kimmins 1987) that prevent further development of the vegetation. Western redcedar leaf litter can restrict the growth of understory species, although often mosses can tolerate these conditions and will initiate growth of other species. With the exception of alien invasive species, the issues with phytotoxic exudates are not generally significant.

4. Propagule availability

Another biotic filter that may be important on large disturbances on in areas where mature forests border the disturbed areas is a lack of plant propagules. On large sites or on sites where the surrounding vegetation is in a late successional stage and there are no pioneering plants nearby, the ability of plants to colonize the bare ground may be so slow that erosion and other problems might arise before the pioneering plants can establish an effective cover. Establishment of pioneering species can be important in situations such as this. Seeding in pioneering woody species such as alder can be an effective treatment on large sites.

5. Facilitation

Facilitation (Temperton et al. 2004) is often considered a beneficial ecological process. Pioneering species may facilitate the growth of later successional species. However, facilitation can promote the growth of one species over another. For example invasive nitrogen fixing species might promote the growth of nitrogen-loving plants at the expense of other more thrifty species. Within the context of restoration however, the facilitation effect of pioneering species on later successional species is an important attribute of these systems (Walker et al. 2007).

6. Species interactions

There may be specific interactions between species such as between a vascular plant and a pollinator without which the plant in question will suffer. Enhancing the diversity of the restored ecosystem will help to ensure that beneficial species interactions are available. In many cases redundancy in these interactions helps to promote development of the ecosystem (Falk et al. 2006). Having many pollinators available by creating a diversity of appropriate habitats can help ensure redundancy and hence resilience (Holling 1973).

Succession as a model for success

Natural successional processes provide an excellent model for the restoration of drastically disturbed sites (Polster 1989). Pioneering species such as willows, poplars, and alders can be used to initiate successional processes on bare soil or rock sites. These species produce large quantities of biomass that can quickly create soil-like materials amenable to later successional species. Alders fix nitrogen and can increase biodiversity through a process known as niche complementarity (Kahmen et al. 2006). The role of pioneering species in taking sites from bare ground to a vegetated condition that initiates successional trajectories is well known (Polster 1989; Walker et al. 2007).

Providing pioneering species as the initial stage in restoration of drastically disturbed sites has benefits in a world with uncertain climate futures (IPCC 2007). These species have broad ecological amplitude so can provide recovery services under a broad range of climatic conditions. In addition, by avoiding the temptation to try to guess the species composition of later successional stages decades in advance of their establishment, the use of pioneering species initiates successional processes that do not dictate the specific species composition of later successional stages. The appropriate later successional species composition will establish naturally when the time comes.

Using natural successional processes as a model for the restoration of drastically disturbed sites is cost effective. The pioneering species that are used are often easy to propagate and are designed to spread into un-vegetated areas. In addition, propagules of these species (seeds or cuttings) are often available for the cost of collection in the project area. Pioneering species often show remarkable survival and growth on very harsh sites as these are the conditions to which they are adapted. Leader growth of a meter or more per year is not uncommon for many of these species. The ability to grow rapidly and occupy the disturbed site quickly helps to reduce problems with invasive species as well as providing evidence to stakeholders that the restoration is effective. By following the natural recovery processes, successionally based treatments can take advantage of many recovery elements that happen without costly interventions.

Conclusions

Restoration programs that are modeled on the natural processes that have been restoring natural disturbances for millions of years and are ideal for re-establishing the ecological functions, goods, and services that have been lost when the degradation occurred. Because the actual processes that formed the ecosystems initially are used to assist in the recovery of the ecosystems, the use of natural processes such as succession and nutrient cycling are very effective in returning the ecological values associated with the ecosystem.

Identification of the filters or constraints that are preventing recovery of the ecosystem is the first step in the restoration process. In most cases, once the filters have been identified and addressed, the recovery of the site is simple. Avoid creation of additional filters as part of the treatment. For instance, seeding a site with agronomic grasses and legumes, except where a tame pasture or hayfield is desired, can establish a successionally stagnating cover of these species. Excessive grading and smoothing sites serves to increase compaction and creates conditions that open the site to erosion. Making sites rough and loose (topographically heterogeneous) can: eliminate compaction; reduce erosion; create micro-sites for the seeds of native pioneering species to lodge in; and a diversity of edaphic conditions. Inclusion of large woody debris, brush piles, boulder piles and other such features can greatly enhance recovery processes by providing ecological heterogeneity in the site conditions. Increased diversity is the reward for a heterogeneous site.

Native pioneering species that operate in the area are selected as the species of choice for the initial vegetation establishment. These are generally readily available in the local area for the cost of gathering the propagules (seed or cuttings). Pioneering species are generally easy to establish and need little or no maintenance. Growth rates of pioneering species are generally exceptional on the adverse substrates that are common with disturbed sites. These species will quickly build soils on barren sites and create conditions that will foster the growth of later successional species.

The use of natural processes can greatly reduce the costs associated with recovery of disturbed sites. By harnessing the power of natural recovery, the natural processes model greatly reduces the cost of treatments and generally eliminates the need for costly maintenance or re-treatments. By allowing the established pioneering species to create conditions appropriate for subsequent species, accommodation for changes in climate is built into the use of the natural processes model. Following natural processes creates ecosystems that are appropriate for the conditions of the area and the end land uses that might be applied.

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8. *Influence of active versus passive forest road restoration on ecohydrologic structure and function over time in the Clearwater National Forest, Idaho*

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With more than 850,000 kilometers of roads on public lands in the United States, and many of these roads now classified as surplus to management needs, road reclamation (also called road decommissioning) has emerged as an integral part of resource management and restoration strategies. However, there are no consistent prescriptions for how road reclamation should be implemented to restore ecosystem structure and function of forested lands. Managers are limited by critical research gaps on how road reclamation method enhances ecological and hydrological recovery.

We examined two road reclamation prescriptions:

1. Recontour or active road reclamation (using heavy equipment to excavate the road prism and restore natural slope) compared to
2. Abandon or passive treatment (allowing a road to revegetate over time).

We compared how the two approaches affect ecosystem recovery over time relative to never-roaded areas on the Clearwater National Forest in northern Idaho. Results show above ground ecological recovery to be similar between abandoned and recontoured sites, whereas below ground ecosystem properties were strikingly different. Infiltration rates and water storage capacity on recontoured roads increase with restoration age and are significantly greater than on abandoned roads. In addition, rooting depth was limited to the upper 10 cm on abandoned roads even after 50 years of tree growth, whereas rooting depth on recontoured roads and never-roaded reference areas were below the limits of excavation of 100 cm. Finally, results show substantial differences in distribution of soil organic matter, soil carbon, soil nitrogen, and nutrient cycling rates across road treatment types, with soil organic matter nearly two times greater on recontoured roads than on abandoned roads. Total soil carbon and nitrogen were orders of magnitude higher on recontoured roads after only 10 years of recovery compared to roads abandoned for over 50 years. Limitation on rooting depth, water storage, and differences in soil organic matter, carbon, and nitrogen suggest that the compaction from road building and traffic still exists after 50 years of passive restoration. In our study, it appears that restoration prescription determines recovery potential.

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9. Roads as vectors for the introduction and spread of invasive plants

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Invasive plants are any alien plant species that have the potential to pose undesirable or detrimental impacts on humans, animals, or ecosystems. They have the capacity to establish quickly and easily on both disturbed and undisturbed sites, and can cause widespread negative economic, social, and environmental impacts.

Noxious weeds are invasive plants that have been designated under the *BC Weed Control Act* (see http://www.agf.gov.bc.ca/cropprot/noxious.htm). This legislation imposes a duty on all land occupiers to control a set list of identified invasive plants. An "occupier" means a person who:

- is in physical possession of land, premises or property; or,
- is responsible for, and has control over, the condition of, the activities conducted on and the persons allowed to enter or use, land, premises or property.

For this *Act*:

- There may be more than one occupier of land, premises or property;
- A municipality may be an occupier of land, premises or property; and,
- The government may be an occupier of land, premises, or property.

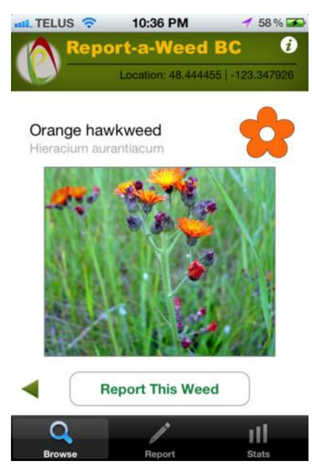
Roads can act as vectors of spread into neighboring habitats (wind, animals, ditches, vehicles, construction, maintenance, reclamation treatments). Best Practices have been developed for managing invasive plants along roadsides.

Summary of Best Practices

1. Identify
2. Plan
3. Record and report
4. Keep equipment clean
5. Minimize disturbance
6. Retain desirable vegetation
7. Coordinate activities
8. Practice effective mowing and brushing
9. Ditch effectively
10. Manage source and waste material
11. Control weeds
12. Restore

1. *Identify invasive plants:*
   - Consult invasive plant inventory and treatment maps such as the provincial government's Invasive Alien Plant Program (IAPP): http://www.for.gov.bc.ca/HRA/plants/raw.htm
   - Or use the app for mobile devices, available at: http://reportaweedbc.ca/ .

2. *Plan maintenance activities accordingly:*
   - Follow Best Practices;
   - Determine local problem plants.
   - Contact East Kootenay Invasive Plant Committee prior to planning maintenance activities, at 1-888-55-EKIPC.
   - Or, contact the regional committee for your part of the province. See information at: http://www.bcinvasives.ca/general/regional-committees



3. *Record and report invasive plants*
   - All field personnel are your "eyes on the ground". Give them plenty of resources.
   - Ensure invasive plants are recorded and reported.
   - Use Report-a-Weed Online or the Report-a-Weed Mobile App. See: http://reportaweedbc.ca/

4. *Keep equipment clean*
    - Avoid parking, turning around, or staging equipment in invasive plant infested areas; or mow the areas prior to use.
    - Wash equipment after returning it to the maintenance yard.
    - Inspect and clean vehicles before entering a weed free area, and before leaving an infested area.

5. *Minimize unnecessary disturbance* of roadside aggregates or soil.

6. *Retain desirable vegetation* where possible.

7. *Coordinate activities*
    - Establish annual vegetation control schedule in collaboration with the local spray contractor and regional weed committee.
    - Do not brush or mow seven days before or after an herbicide treatment.
    - Inquire about residual herbicide on ditch material before relocating it.

8. *Practice effective mowing and brushing*
    - Where possible, begin mowing or brushing in "invasive plant free" areas and end in infested areas.
    - Implement full width mowing around wells and areas where herbicides cannot be applied.
    - Avoid mowing grasses and vegetation lower than 15 cm above ground level.
    - Mow or brush invasive plants prior to seed set.
    - Shut off and raise equipment when selectively cutting areas.

9. *Ditch effectively*
    - Do not dump ditch waste above or below the ditch where desirable vegetation is established
    - Dispose of infested waste to a designated disposal site and report.
    - Where it is necessary to side-cast, ensure any material deposited on existing vegetation is spread evenly and reseeded.

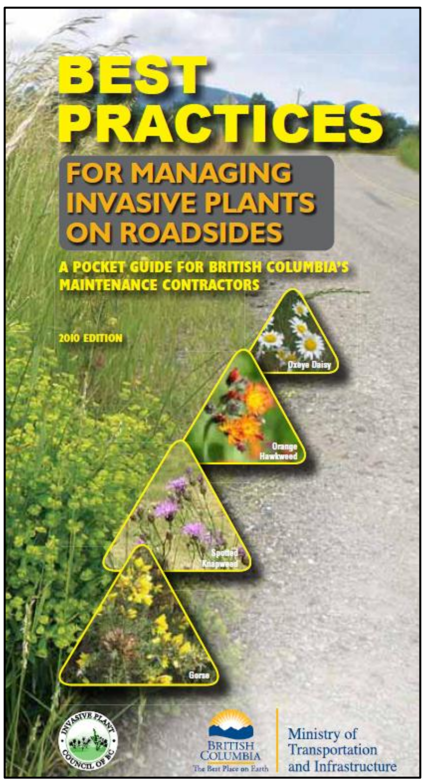
10. *Manage source and waste materials*
    - Use only clean fill material from an "invasive plant free" source.
    - Dispose of soil containing invasive plants in a designated spoil pile.
    - Regularly inspect all material sources to ensure they are invasive plant free.
    - Record and report invasive plant infested gravel pits and spoil piles.

11. Control invasive plants prior to seed set

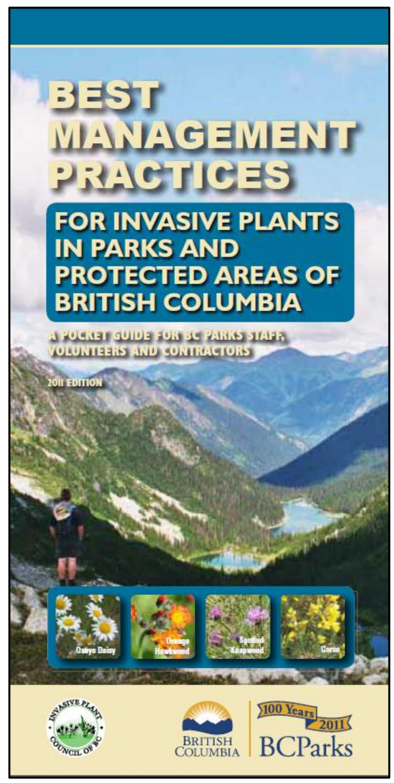
- Chemical treatment
- Hand pull
- Mow
- Access management

12. Restore disturbed sites

- Re-grade disturbed soils and remove unsuitable waste material.
- Re-seed with grass mixtures that are free of weeds, locally adapted, non-invasive, and quick to establish.
- Spread seed in the early spring or late fall to aid in successful establishment.



Best Practices for Managing Invasive Plants on Roadsides
http://www.th.gov.bc.ca/publications/eng_publications/environment/ManagingInvasivePlants.pdf



Best Management Practices for Invasive Plants in Parks and Protected Areas of British Columbia
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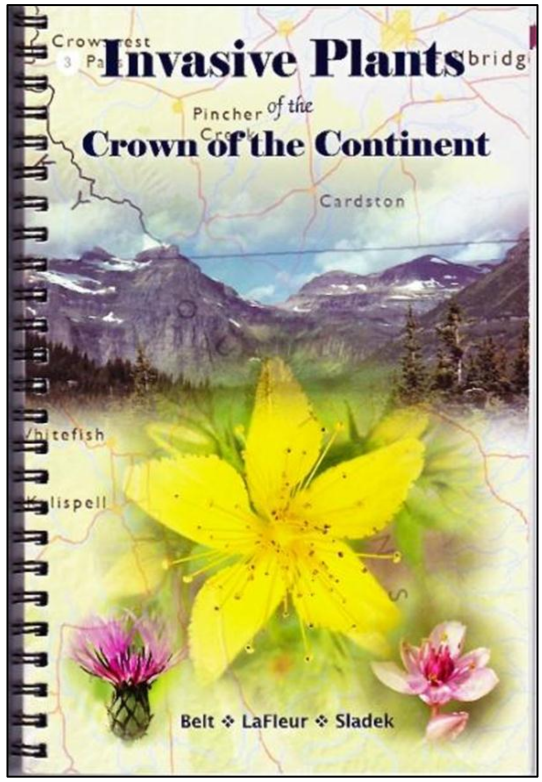

Targeted Invasive Plant Solutions (T.I.P.S.)
http://www.bcinvasives.ca/resources/outreach-materials/invasive-plants-tips

Invasive Plants of the Crown of the Continent
http://www.friendsofkootenay.ca/sites/default/files/Invasive-Plants-of-the-Crown-of-the-Contient.pdf

East Kootenay Invasive Plant Council
Website: http://www.ekipc.com/

Invasive Species Council of British Columbia
http://www.bcinvasives.ca/

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10.Cost effective road mitigation for amphibian populations

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Amphibian ecology and roads

Amphibian populations have undergone dramatic declines globally – approximately 1/3 of amphibians are threatened with extinction. Habitat loss and degradation are cited as the greatest threats to amphibian populations. Rural and urban development and resource management have led to the construction of thousands of kilometres of roads across British Columbia, which results in both a loss and fragmentation of critical habitat (wetland and forest cover). As with all wildlife, increased isolation among amphibian populations leads to decreased genetic diversity, increased risk of mortality, and population declines. To counter the effects of habitat fragmentation, management regimes need to take a landscape-level approach to habitat management (e.g., to maintain connectivity).

Main road issues

There has been increasing interest and concern over the impacts of roads on wildlife such as amphibian populations. For example, several times each summer the media present stories about numerous Western Toad (*Anaxyrus boreas*) crossing sites. A new field of study, road ecology, has formed as a result of the interest and concern associated with wildlife road issues. Studies have taken place or are ongoing investigating the impacts of roads. The true impact of roads on local populations is difficult to discern. Surveys investigating impacts of direct mortality along roads often lack the detailed information regarding population demographics required to fully understand the long-term impacts. For example, often little is known about the proportion of the population crossing a road versus dispersing in other directions (e.g., away from the road). Long-term, detailed data sets are needed to know what the true impacts of a road are on a local population.

Roads can act as both attractants and as barriers for amphibians.

- As ectotherms, amphibians are attracted to the thermal capacity of the road surface (i.e., bask on roads for heat). They may also find roadsides attractive habitats due to the type of cover or vegetation found there, which may provide unique foraging opportunities.

- The design and construction of roads often leads to the creation of wet depressions or aquatic habitats. Water and moisture can be found in road ruts, storm water ponds, and ditches. Amphibians use this ponded water for breeding and ditches as travel corridors.
- Roads can also act as barriers for amphibians. Some species may not attempt to cross certain roads. If they do, it can result in direct mortality.
- Concrete medians used along road edges and along the centre of some roads can be physical barriers.
- Roads also expose amphibians to predators and extreme climatic conditions.
- Stream amphibians are affected by perched culverts, and
- All aquatic species are negatively affected by contaminants associated with roads that may run into streams, ponds, and ditches (e.g., oils, salts, sediment, and garbage).

Roads impact amphibians in a number of ways. Their construction leads to a direct loss and degradation of wetland habitat and forest cover. Small wetlands in particular are vulnerable to infilling and changes to their hydrology. Increasing road density leads to habitat fragmentation. Amphibians are vulnerable to direct mortality (e.g., when basking on roads) and indirectly roads may lead to the creation of sink habitats (e.g., storm water ponds with insufficient hydroperiod). Roads can contribute to pollution through contaminants (spills) and sedimentation (road runoff).

Roads and ditches can also facilitate the introduction and spread of non-native and invasive species. For example, we are initiating a study in the Powell River area investigating the potential that logging roads and associated ditches and sump ponds are facilitating the spread of the non-native and invasive American Bullfrog (*Lithobates catesbeianus*).

Not all roads are created equal and hence, the vulnerability of amphibian species and road conditions are linked. The main factors that influence the vulnerability of specific amphibian species to mortality on any given road are the velocity of the species' movement, the diurnal movement pattern of the species, and the diurnal movement pattern of the vehicles using that road. Therefore, the most vulnerable amphibian species are day active and slow moving. Two such species are the Roughskin Newt (*Taricha granulosa*) and Western Toad. The former is common and abundant on the coast, but vulnerable to road mortality because adults move slowly and both day and night. The Western Toad is a species of Special Concern federally that has experienced population declines in the U.S., and on the south coast of British Columbia. It is vulnerable to urban and rural development because adult toads are attracted to roads, using them for basking and as travel corridors. However, adults tend to only travel on roads after dusk so the diurnal movement pattern of traffic is important. Toads also have numerous synchronous behaviour patterns that make them vulnerable to roads—for example, the toadlets disperse en masse often in one main direction. As a result, the majority of one cohort can be affected by any roads that lie within that dispersal trajectory. Given the ecology of amphibians, roads with the greatest impact are those bisecting or adjacent to aquatic habitats (natural or man-made) and with high traffic volume, especially those with both day and night use, high activity during the amphibian breeding season, and high activity during rain events and rainy seasons.

Mitigation measures

Amphibian populations are affected by the ways in which roads alter hydrology and water quality. The design and choice of location for a road can result in changes to natural flow regimes. To minimize these effects, the natural flow patterns and seepage of precipitation (i.e., into the ground *versus* offsite) should be maintained. To avoid creating sink habitats or facilitating the movement of non-native species, the collection of water in ditches, the creation of sump ponds, and the duration of standing water should be minimized. In addition, spills, sediment runoff, and perched culverts should be avoided (e.g., use box culverts). Traffic patterns in relation to amphibian diurnal and seasonal activity patterns should be considered (e.g., during construction or maintenance projects).

Other mitigation measures that have been employed include the use of seasonal road closures, educational signage (speed limits, flashing signs), and wildlife underpasses with directional fencing. For now, wildlife underpasses are our best-guess solution at maintaining habitat connectivity and facilitating road crossings for amphibians, but more research is needed. To be effective, wildlife underpasses must:

- direct amphibians into suitable habitat (future development must be taken into consideration);
- must be as short and wide as possible (allow light);
- be moist with moderate temperatures; and,
- provide cover from predators.

Most importantly, wildlife underpasses must include directive fencing to force amphibians through the underpass. On-going maintenance and monitoring are required and must be factored into the funding base. Effective directive fencing follows a ‘W’ angle / direction towards the underpass, is at least 0.5 m tall (species specific), is straight, erect, and tight (i.e., no folds), does not have any gaps, and the top is bent over toward the migrating population.

Using small wetlands in mitigation and compensation

Another mitigation approach is the use of constructed small wetlands. The goal with this approach is to reduce the impact of industrial development on local amphibian (wetland associated) populations. This approach can meet multiple objectives:

- wildlife mitigation / compensation (e.g., for species at risk);
- road closure / decommissioning, and
- blocking public access in problem areas (e.g., due to issues associated with poaching, vandalism, dumping, etc.).

The major advantages to this approach include the fact that the work is being conducted in an already disturbed environment, it is cost effective, and it can contribute to forest certification or other environmental practices. The three main construction techniques use groundwater or surface water (through the use of a liner or clay soils). Time and cost increase for surface water wetlands made with a machine or the use of a liner, but most road surfaces are conducive to this technique. Road beds that are deep or that do not allow access to ground water, or roads located in dry areas, are not appropriate for this technique. A 40’ x 60’ wetland can be constructed in one day and costs approximately $6,000 to $10,000 including expert consultation, equipment, and machine time and operator.

The habitat features to take into account when designing a wetland for amphibian populations include:

- cover and foraging habitat (e.g., emergent vegetation, silt bottom, upland / riparian habitat, connectivity):
- wetland size (e.g., > 0.25 ha is relatively “large” for amphibians);
- ponds < 100 m^2 (0.01 ha) are used less for breeding (e.g., by Red-legged Frog);
- suitable egg laying habitat (e.g., submerged or emergent vegetation, thin-stemmed graminoids, branches, wood);
- hydroperiod (wetland should hold water until mid-August); and,
- little to no flow or water movement (e.g., < 5 cm/sec.).

Recommended reading

Various authors. 2011. Herpetofauna and roads workshop: Is there light at the end of the tunnel? Province of B.C. et al. http://www.env.gov.bc.ca/wld/frogwatch/docs/2011/Herpetofauna_and_RoadsWorkshopProgram_Feb222011.pdf

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11.Fish passage in British Columbia – Status, issues and solutions

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Why did the fish cross the road? Read on...the answer will be obvious!

Introduction

There are approximately 550,000 km of resource roads in British Columbia, with an estimated 320,000 crossings of fish streams. Based on culvert assessments done to date under the fish passage program, as many as 70%, or about 224,000, of these crossings are expected to be closed-bottom culverts. Of those closed-bottom culverts, about 60–90% (135,000 to 200,000) are likely to impede fish passage. Closed bottom structures (culverts) can act as a barrier to fish mainly due to increased water velocity, turbulence, a vertical drop at the culvert outlet, and/or maintenance issues.

Considering only the crossings with highest quality habitat, priority fish species, and the most egregious blockages, there are tens of thousands of fish stream crossings that currently require remediation in British Columbia, and therefore thousands of kilometres of quality fish habitat that are under-utilized.

This paper will outline the basis for these conclusions, explain recent efforts to address the problems, and chart a course of the next steps that are required to help British Columbia deliver on the goal of world-class fisheries management, bar none.

Implications of poor connectivity of fish habitat

Fish passage failure at steam crossings constitutes a major loss of freshwater habitat for both migratory and resident fish populations in British Columbia (Northcote and Hartman, 2004).

Loss of habitat is a major threat to freshwater species at risk such as west slope cutthroat trout, bull trout and others.

Fish form an integral link in aquatic and terrestrial ecosystems. For example, salmon returning to spawn are a major source of marine-derived nitrogen and their absence can impact an entire forest ecosystem, from grizzly bears to tree growth (SFU 2008, Field and Reynolds 2011).

The isolation and restriction of fish populations can affect gene flow and lead to populations less able to adapt to changing conditions.

Freshwater sport fishing supports the British Columbia economy. In 2005, anglers spent $480 million in British Columbia, creating 3,875 person-years of employment and contributing $125 million in tax revenues (GS Gislason & Associates Ltd. 2009).

Recent history of the fish passage issue in British Columbia

The provincial government's Ministry of Forests, Lands and Natural Resource Operations, the Ministry Environment, and the federal Fisheries and Oceans Canada have long been aware of issues associated with fish passage through culverts, and for many years were addressing those concerns in local, ad-hoc ways. One excellent example is the report by Harper and Quigley from 2000.

Stream crossings that were built before the Forest Practices Code legislation was passed in June 1995 are solely government's responsibility to maintain and to remediate where required. Dedicated funding for fish passage restoration work began in 1995 when the British Columbia government introduced the Watershed Restoration Program under Forest Renewal BC (FRBC). The program was designed to restore, protect and maintain forest resources, including non-timber values such as fisheries, which had been adversely impacted by past forest management activities. Funding for fish restoration and rehabilitation was reshaped in 2002 with the introduction of the Forest Investment Account (FIA). In 2007, with direction from the Ministry of Forests, Ministry of Environment, and Department of Fisheries and Oceans Joint Management Committee, targeted funds were allocated to specifically set priorities and fix the pre-1995 problem fish stream crossings.

In 2009 the Forest Practices Board surveyed over 1,100 crossings across 19 watersheds and found that closed-bottom structures, which include culverts, posed a moderate to high risk to fish passage about 90% of the time on important and critical fish habitat and 96% of the time on marginal habitat. In response to these findings, the Board recommended that the "government take the necessary action to ensure fish access is maintained and restored". (See: http://www.fpb.gov.bc.ca/publications.aspx?id=3714)

In 2010, funding for the Fish Passage program was shifted to the Land Based Investment Program (LBI), and the Fish Passage Technical Working Group (FPTWG) was charged with administering the funds to achieve government objectives.

Developing the strategic approach to fish passage remediation

After collaborating on the original Fish-stream Crossing Guidebook (2002), and monitoring its implementation during the Forest Practices Code days, and with evidence mounting on the magnitude and distribution of impeded stream crossings, the Government of British Columbia together with Fisheries and Oceans Canada, the Council of Forest Industries, and the Coast Forest Products Association, determined that government should play a larger role in prioritizing future restoration activities. Starting in 2007, those agencies produced the Strategic Approach: Protocol for Planning and Prioritizing Culverted Sites for Fish Passage Assessment and Remediation (now in third edition, 2009).

The objective of the strategic approach is to ensure that the most important fish passage issues can be identified and restored in a cost effective manner. The process is systematic and efficient in its design. The approach is also flexible and can be implemented at various scales while still maintaining provincial applicability. The approach has four key components:

1. Identify high value fish watersheds to focus work;
2. Develop and apply in a systematic manner a standardized assessment methodology to determine fish passage;
3. Review data from all culverts assessed in a watershed area so that repair of the highest priority problem culverts can be carried out; and,
4. Monitor to ensure objectives are being achieved.

This strategic approach outlines the process for undertaking a systematic, watershed-based approach to assessing and prioritizing fish passage at culverted stream crossings. This process covers project planning through to implementation. It is to be used in conjunction with the companion document "Field Assessment for Fish Passage Determination of Closed Bottomed Structures " (Field Protocol), which provides the detail for the field data collection phase of the overall process. (NOTE: the assessment methodology is covered in more detail in the paper delivered to this workshop by Richard Thompson.)

The strategic approach is based on Ministry of Environment's GIS stream model, and TRIM-based roads data, which together identify stream crossings on fish habitat, and combines this with assessment data that have verified problem sites and fish habitat. Together these two data inputs are used to identify the highest priority remediation projects in terms of the potential to gain high quality fish habitat.

The roles of the Fish Passage Technical Working Group

The Fish Passage Technical Working Group (FPTWG) was formed in 2007 following a directive from the inter-agency Joint Steering Committee. Members of the FPTWG currently include representatives from the Ministry of Environment; Ministry of Forests, Lands and Natural Resource Operations (including BC Timber Sales), Ministry of Transportation and Infrastructure, and Fisheries and Oceans Canada. Efforts are also underway to include the Ministry of Energy, Mines and Natural Gas, and the Oil and Gas Commission.

The overarching goal of the FPTWG is to raise awareness of the fish passage problem at stream crossings and to identify and implement solutions. The work carried out by the FPTWG is currently funded through the Land Based Investment Program – Fish (formerly Fish Passage Program). The FPTWG, however, is also working to expand its network of partners (and funding sources) to target the remediation of stream crossings on all roads (rather than just pre-1995 forest roads), and to ensure that the installation of new culverts is done in a manner that does not impede fish passage.

Specific objectives of the FPTWG are to:

1. Refine the scope of the problem through a combination of field assessments and GIS analysis;
2. Develop and refine the strategic approach for selecting remediation sites, which will provide the greatest return on investment in terms of amount of high-value fish habitat restored;
3. Allocate funding to remediate road crossing sites which block fish passage;
4. Conduct targeted training and extension, and provide guidance to practitioners; and,
5. Identify and acquire funding for stream crossing remediation.

Under FRBC and FIA and until fiscal year 2009/2010, the Fish Passage Program (like other FIA programs) was proponent-driven, with licensees identifying projects and applying for funds to complete the work. During that time, PriceWaterhouseCoopers, a third party administrator, played a major role in the delivery of the program by approving applications and managing funds. This delivery model began to become more focused on meeting government's objectives in 2007 with the establishment of the Fish Passage Technical Working Group.

As of the start of fiscal year 2011/2012, the fish passage program of Land Base Investment is no longer proponent driven. Although a third party still provides administrative support and financial management to other Land Based Investment programs, the Fish Passage Technical Working Group (FPTWG), rather than licensees, now identifies high priority watersheds for assessments and crossings for remediation. The FPTWG now works directly with BC Timber Sales to complete assessments and to restore crossings.

Accomplishments to date

In addition to achieving a higher level of engagement of government agencies, with closer aligned to government objectives, the key "on the ground" accomplishments are summarized in Table 1.

Table 1. *On-the-ground accomplishments of the Fish Passage Technical Working Group*

Fiscal Year	Expenditures (millions)	Assessments	Installed Culverts*	Installed Bridges*	Remediation (general)	Fish habitat recovered (km)
2008/09	$6.1	4,683	27.5	16.5	-	158
2009/10	$3.6	4,594	23	11	-	184
2010/11	$2.4	8,171	-	-	17	305
2011/12	$1.5	1,987			2	25
2012/13	$2.0	3,000			*18 (includes 11 deactivations)	*27
Total	**$15.6**	**22,435**	**50.5**	**27.5**	**39**	**699**

With this large influx of culvert assessment data, it became clear that the Excel spreadsheet being used was insufficient, and that a proper database was necessary to store, analyze, and communicate the data. The team has developed the Provincial Stream Crossing Information System (PSCIS; pronounced "pisces"), a new spatially referenced database which houses information about assessments, designs, and completed installations. This "one-stop" database allows the FPTWG to identify areas of high priority, coordinate the delivery of the fish passage restoration work, and share information with licensees and other delivery partners. The database, and the underlying modelling that informs the strategic approach, are explained in more detail in the presentation to this workshop by Craig Mount.

Another important accomplishment of the FPTWG is the revision of the Fish-stream Crossing Guidebook, published in September of 2012. Nearly one thousand paper copies have been distributed to key practitioners and decision makers around British Columbia, and a limited number will be handed out during this workshop. Additional copies can be downloaded from the FPTWG's webpage at:

Fish-Stream Crossing Guidebook, Revised Edition, September 2012.
http://www.for.gov.bc.ca/hfp/Fish/Fish-stream%20Crossing%20Web.pdf

The FPTWG has been working on creating a series of on-line training courses on fish passage. To date, the group has completed the first module, which outlines the strategic approach, and presents the details on culvert assessment methodology. Further module(s) on fish stream crossing design, installation, and maintenance are in the planning stages.

Lastly, the group has been working on raising awareness of the extent of fish passage concerns, and enlisting partners and other collaborators to address those concerns. Participation in this natural resource roads workshop is a key “awareness” event for the FPTWG this year. We have also delivered less-formal presentations to key stakeholder groups, most recently the advisory committee for the *Natural Resource Road Act.*

Current issues

In respect of the large number of fish-stream crossings that do not provide for adequate fish passage, the most pressing issue is funding. At the current funding level of $1.5 million per year, the province’s ability to have meaningful impact is severely limited. The FPTWG is developing a funding proposal that will (if and when approved) significantly improve our capacity to identify and remediate the highest priority crossings.

The other large issue that is still looming is how to engage a much broader spectrum of agencies, stakeholders, industries, and local governments in collaborating on fish passage. Specifically, there is a need to engage municipalities, regional districts, railroads, and transmission companies, all of whom manage crossings on fish streams. The FPTWG will continue to seek engagement with these entities as time and resources permit.

Next steps and solutions

A key advancement this year has been developing some linkages between the natural resource sector and the Ministry of Transportation and Infrastructure. The next step is to formalize that relationship and to begin collaborative planning of remediation works.

Similarly, another important next step will be expanding the scope of the FPTWG to fully represent the entire natural resources sector within the provincial government. This will entail developing linkages with the Ministries of: Agriculture; Energy, Mines and Natural Gas; and Aboriginal Relations and Reconciliation.

At a more operational level, the FPTWG is actively amending the engineering standards for crossing remediation, and the associated standards for data capture in PSCIS. This year, the group has funded our first crossing remediation works that do not involve merely replacing a poor crossing with a good one; specifically we have funded a road relocation/crossing deactivation project, and assisted with funding a larger road deactivation project, where some of the crossings were on fish streams. Developing decision-making criteria for these types of works compared to more "traditional" replacements is also under discussion.

Last words

To give some perspective to British Columbia's fish passage problems, the FPTWG has recently been in touch with the Washington State Fish and Wildlife program. Even through the worst housing crisis in America's history, the state's forest owners have remained committed to protecting water quality and fish habitat.

Since the state's Forests and Fish Law was approved a decade ago, large forest landowners have improved 18,700 miles of logging roads and opened 4,700 passages for fish and 2,600 miles of fish habitat. Last year was especially productive, with the opening of 1,000 fish passages and restoration of 900 miles of fish habitat. Collaboration works.

The FPTWG is developing the collaborative tools and relationships here in British Columbia that will bring us to similar levels of achievement. Our valuable fisheries resource deserves nothing less.

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Ministry of Forests, Lands and Natural Resource Operations, Fish Passage Technical Working Group
http://www.for.gov.bc.ca/Hfp/fish/fishpassage.html

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12. Assessing fish passage at culverts – The method, its metrics, and preliminary findings from over 8,000 assessments

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There has been a long history of concern regarding road stream crossings as partial or full barriers to fish movement. The past decade has seen the need for a reliable, repeatable method to assess closed bottom structures for their ability to pass fish. British Columbia has adopted a methodology that builds on fish passage assessments developed for the BC Watershed Restoration Program and those used in Washington and Oregon states. The current fish passage assessment methodology uses a series of stream channel and crossing structure measurements to assess the likelihood that a fish will be able to pass through the structure.

This paper addresses:

1. The assessment methodology, the metrics and scoring model;
2. Some of the common problems encountered during application of the assessment; and,
3. Key findings on why culverts fail to pass fish. A preliminary look at the data from over 8,000 fish passage assessments conducted in British Columbia.

As more data is collected we continue to develop a better picture of the size, scope, and reasons for fish passage failures in British Columbia. The data is now spatially available and can be found on iMap BC.

Background

British Columbia is a large province rich in natural resources. In order to gain access to those resources over 550,000 kilometers of road have been developed. Provincially there are over 440,000 road stream crossings or roughly 0.8 crossings per kilometre. Each of these crossings has the potential to impact the riparian and aquatic environment. Stream crossings can result in:

- Direct loss of instream and riparian habitat;
- Changes in aquatic and riparian connectivity such as the movement of fish, amphibians, and small mammals;

- Changes in channel processes such as movement of woody debris, bedload, and sediment;
- Direct entry of pollutants such as sediment and hydrocarbons;
- Changes to downstream habitat and channel through increased velocity or blocking of bedload and woody debris;
- Reductions in species distribution and productive capacity.

The focus of the Fish Passage Technical Working Group (FPTWG) has been on restoring aquatic connectivity, or more specifically, fish passage at road stream crossings. The desired outcome is a crossing structure which allows aquatic organisms to move upstream and downstream as they would in the natural channel. The best way to achieve this outcome is to maintain channel continuity through the crossing by ensuring the streambed is maintained or emulates the natural channel bed and that the stream channel is not constricted (BC Ministry of Forests Lands and Natural Resource Operations et. al. , 2012) by the crossing structure or erosion protection measures (e.g., by rip rap).

With the large number of crossings in the province the task of assessment presents significant challenges. In order to allocate scarce resources efficiently the FPTWG has implemented a strategic approach to assessment and remediation which sets priority watersheds based on fish values (BC Ministry of Environment, 2009). The assessment of structures within those priority watersheds is carried out in a systematic way at road crossings within our modeled fish distribution (Mount et. al, 2011).

How are culverts assessed for fish passage?
The literature presents a number of potential methods to evaluate fish passage at culverts (Robison et al 1999, Washington Department of Fish and Wildlife 2009, US Forest Service 2005, FishXing 2012).

1. Observation, mark-recapture experiments.
2. Velocity measurement.
3. Hydraulic calculations.
4. Hydraulic surrogates.

Each of these methods has advantages and disadvantages. Direct observation (mark-recapture experiments) is difficult and time consuming making them impossible to apply across large numbers of structures. Sampling for fish above a suspect structure, while less time consuming than mark-recapture, requires specialized equipment, training, and time, and such sampling may not result in the determination of fish movement. Fish found upstream may be part of a resident population or have dispersed downstream from a lake. Directly measuring stream velocity, which can be compared to fish swimming ability, is technically challenging and dependent on location of measurements in the stream profile (Kehler, 2009) and the stream flow stage (spring melt *vs.* summer low flow). Hydraulic calculations require specific expertise and knowledge of watershed conditions. Government and industry staff needed a methodology that would be simple to implement, repeatable, and supported in the literature. In order to achieve these requirements the current methodology that relies on hydraulic surrogates was developed.

Current method

The method employed by the FPTWG measures a number of stream channel and structure indicators that allow inference of the hydraulic conditions within the culvert.

Key indicators:

1. Embeddedness
2. Outlet drop
3. Stream width ratio
4. Culvert slope
5. Culvert length.

These indicators are simple to measure, repeatable (they can be done at most stream stages) and can be done in fifteen to twenty minutes at any given site.

What is embeddedness?
This indicator is a measure of the stream bed material within a culvert (Figure 1). Assessors are asked to determine if a natural stream bed continuously covers the bottom of the culvert and the depth of cover. A culvert with a natural stream bed is assumed to have similar roughness and velocity shadows to allow fish to pass through the culvert as if they were in an undisturbed segment of the stream. The depth of material is an important measure, because it relates to the probability of the stream bed being scoured from the culvert, exposing the bare culvert, which results in increased velocity.

Figure 1. *Properly embedded culvert. Streambed is continuous and 40% of culvert diameter.*

What is outlet drop?

Outlet drop is the distance from the invert (bottom) of the culvert to the top of the residual pool (Figure 2). The residual pool is the pool that would remain at the point that water just stops flowing out of the pool. The measurement is made to the residual pool to ensure that the measurement is consistent regardless of the current flow in the stream. Outlet drop is an important consideration as fish have limited ability to jump.

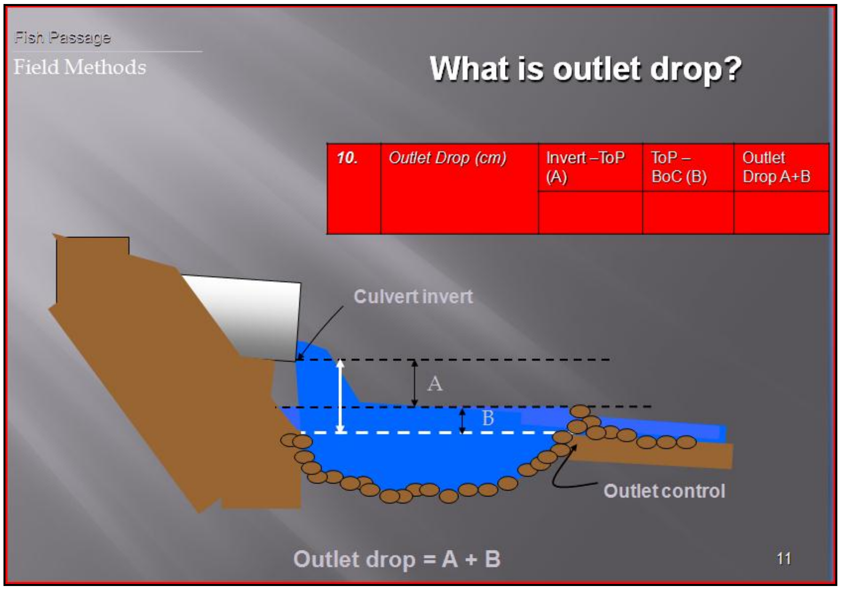

Figure 2. *Outlet drop measured from the culvert invert to the top of the residual pool.*

What is stream width ratio?

The stream width ratio is simply the ratio determined by stream channel width divided by the culvert width. This ratio is an indication of channel constriction (Figure 3) which results in increased velocities within the culvert.

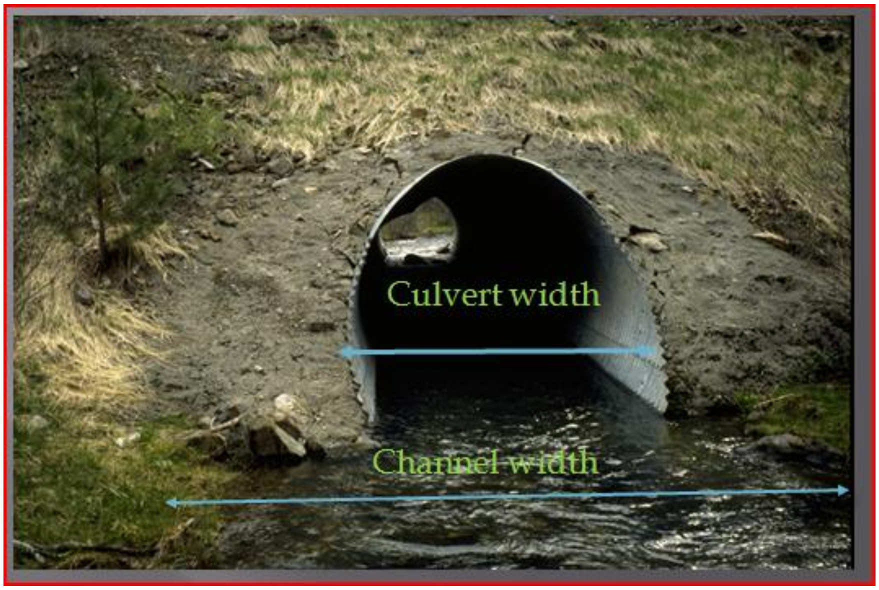

Figure 3. *Stream width ratio.*

What is culvert slope?

This is a measure of the angle of the culvert and is calculated by measuring the difference in elevation from the outlet to the inlet divided by the horizontal distance between the outlet and inlet of the culvert (Figure 4). Flume studies done in Washington State and Manitoba (Powers, 1997; Kehler 2009) have shown that bare culverts at slopes greater than 1.0 % can be a barrier to juvenile salmonid movement. Because such a small difference in slope can be problematic for fish the current methodology calls for the use of an engineering level to more accurately measure the slope of the culvert where the slope as measured with a clinometer is less than 4%. A common error often made by assessors is to assign too high a level of accuracy to clinometers. Clinometers are typically accurate to plus or minus 2%.

What is culvert length?

This is a simple measurement of the length of the culvert from the inlet to the outlet. Fish have limited ability to maintain their highest speed (burst velocity typically 1 to 6 seconds—also known as darting speed). This metric is not independent of culvert slope and stream width ratio but recognizes that a longer, high slope culvert will be more difficult for a fish to pass than a shorter culvert.

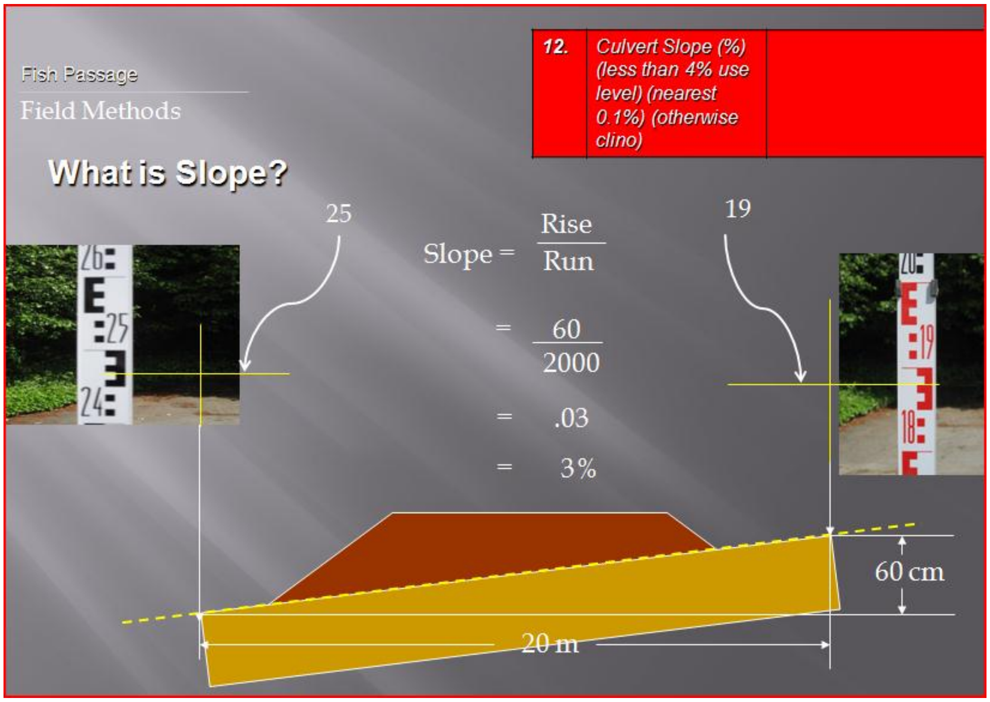

Figure 4. *Culvert slope and length.*

Barrier Determination Model

The measurements made in the field are used to calculate a Barrier determination score. For example, a culvert with no streambed (bare pipe), outlet drop of 20 cm, stream width ratio of 1.2, slope of 2%, and length of 14 meters would have a Barrier score of 23. This number is arrived at by summing the individual values for each of the indicators (Table 1.). Not embedded = 10, Outlet drop 20 cm = 5, Stream width ratio of 1.2 = 3, Slope of 2% = 5, Length of 14 meter = 0.

Table 1. *Barrier determination value for each indicator in fish passage model.*

Risk	Embedded[2]	value	Outlet drop	value	Slope	value	SWR	value	Length	value
low	> 30 cm. or > 20% of Diameter and continuous	0	< 15	0	< 1	0	< 1.0	0	< 15	0
mod	< 30 cm. or 20% of Diameter but continuous	5	15 - 30	5	1 - 3	5	1.0 - 1.3	3	15 – 30	3
high	No embeddment or discontinuous	10	> 30	10	> 3	10	> 1.3	6	> 30	6

Once the assessor has determined the score for an individual culvert, that score is put in to one of three categories. Scores of 20 or greater are considered a barrier (Table 2). A structure with a score of 15 to 19 is classified as a potential barrier and should undergo further detailed analysis if it is to be considered for restoration.

Table 2. *Barrier determination score outcome.*

Cumulative Score	Result
0 - 14	passable
15 - 19	potential barrier
20 or greater	barrier

The values associated with each of the indicators in the barrier determination model were developed based on information available on fish swimming ability which is a function of species and size (Figure 5). A juvenile Coho does not have the same swimming ability as an adult Coho; similarly an adult Grayling is a weaker swimmer than an adult Steelhead. The indicator scores reflect the best estimation for the passage of a juvenile salmon or small resident rainbow trout.

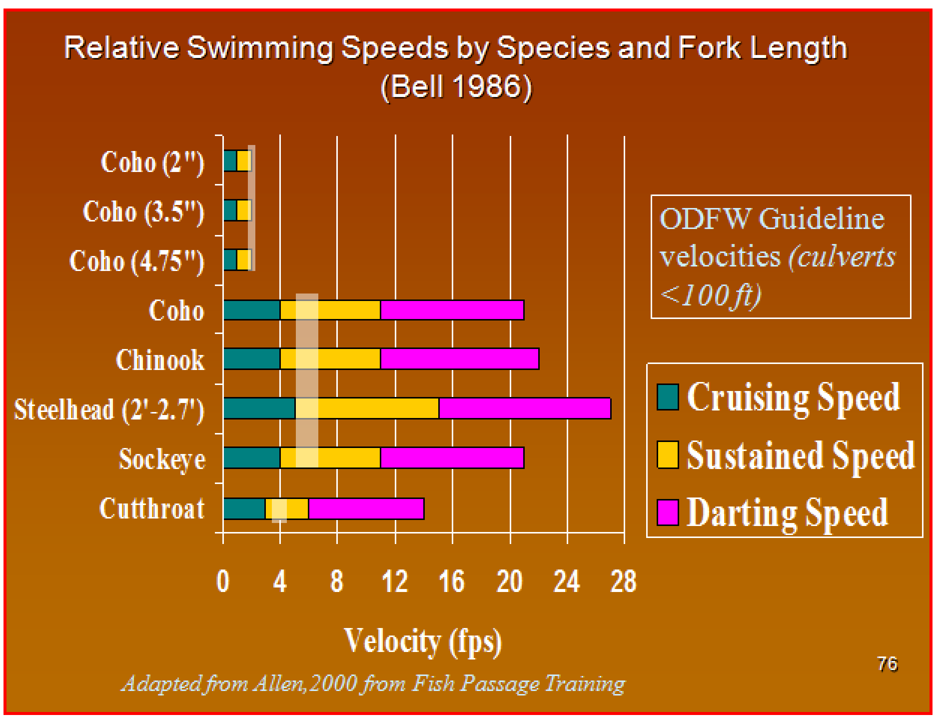

Figure 5*. Fish swimming ability.*

Preliminary findings

The Provincial Stream Crossing Inventory System (PSCIS 2011) as of November 1, 2012 had data for 4,870 culvert assessments. The number of structures in the database is growing as legacy data is loaded and as new assessment projects are completed. All of the data is available to the public and can be accessed through iMap BC (iMap 2012). To access data in iMap, add layers and then click on the physical infrastructure layer to find the PSCIS data.

For the purpose of the Columbia Mountains Institute's Resource Road workshop we summarized the current data for two spatial areas: the Province and the Kootenay Natural Resource Region (Table 3). The total failure rate for the culverts assessed is 71% or 3,458 structures that fail to meet our fish passage criteria. The database contains crossing assessments from all regions of the province. The data shows some variability in the failure rate from watershed to watershed, and region to region, but consistently in every watershed that assessments projects have been conducted a proportion of the fish stream crossings with culverts installed fail to meet the criteria for fish passage. In the Kootenay region 61% or 844 of the 1,384 assessed culverts are problematic. If the average cost to restore a failed crossing structure is $50,000 then identifying the top 10% of the currently known failed structures in the Kootenay region would cost over 4 million dollars.

Why do they fail?

Over 40 % of the structures both provincially and in the Kootenays have significant outlet drops (greater than 30 cm). Probably more importantly, over 70% of the crossing structures constrict the channel resulting in increased velocities through the culvert which often results in downstream channel changes. The scour and restriction of bedload movement can in time result in the development of an outlet drop.

Table 3 *Culvert Assessment Summary*

	Province	Kootenay
Number	4870	1384
% Fail	71	61
% Outlet Drop >30 cm	43	47
% Stream Width Ratio > 1	74	78
% Slope >1%	77	81

Fish regularly move through natural channels with average slopes of up to 10% (Hoffman 2007). The Forest Practices Code of British Columbia specified that streams with no fish information would default to be a fish stream if the gradient was less than 20%. In natural channels fish are able to use natural velocity shadows associated with boulders, woody debris and other channel complexity to rest and then dart through areas of higher velocity(higher slope). Close to 80% of the culverts assessed provincially and in the Kootenays have slopes greater than 1% and over 50% have slopes greater than 3%. Bare culverts at these slopes present significant challenges for juvenile or small resident fish to pass.

The most significant finding from assessments done to date is the high proportion of structures that constrict the channel. Channel constriction and its associated increase in velocities often lead to other issues such as outlet drop and loss of embedment material.

Common problems or challenges in applying the assessment methodology

The Fish Passage Assessment methodology (BC Ministry of Environment, 2011) is updated periodically to clarify issues assessors have identified.

One of the most helpful items used to review assessments is the photos; unfortunately these remain one of the items assessors often forget. Submission of field data to the PSCIS requires five photos, inlet, outlet, upstream, downstream and the barrel of the culvert.

When can I do assessments?
The assessment method was designed to be done at any time, any flow—however safety and visibility are a concern. High flows can make many streams too dangerous for assessment. High flows and snow can visually obscure stream banks and bed making it difficult to complete assessments.

How do I deal with multiple pipes?
For the barrier determination use the metrics from the pipe lowest in elevation at the outlet. For pipes installed at the same elevation at the outlet, add diameters for stream width ratio criteria and use the highest slope, and length measurement.

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13. Habitat modeling and culvert assessments to determine the scope of the fish passage problem in British Columbia

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The majority of this presentation was based on a methodology paper that was written for *Streamline* last year. The link to that paper is provided below for those interested in the details of the modelling.

Abstract

Being a large province with vast areas of resource development, British Columbia has a significant number of roads (>550,000 km) that travel throughout its diverse regions. Most of these regions also have valuable surface water resources in the form of rivers, streams, and creeks. When these two types of linear features invariably cross, the result is the need for some type of crossing structure to be built as part of the road prism, be it a bridge or culvert, depending on the sizes of the watercourse and the transportation feature. Conservative estimates place the number of culverted crossings in British Columbia at more than 430,000.

While open bottom structures such as bridges and some larger culverts typically retain or emulate the natural stream channel morphology and fish habitat, smaller, closed-bottom structures (round pipes) often do not. As a result, improperly designed, improperly installed, or improperly maintained closed-bottom culverts and the consequent isolation of thousands of kilometres of fish habitat is one of the greatest threats to many populations of native British Columbia fish species which have a migratory component to their life cycle—anadromous and otherwise. Lack of fish passage at culverts is becoming widely recognized and acknowledged as one of the largest impacts to fish habitat in British Columbia.

Since 2007, a multi-agency provincial and federal Fish Passage Technical Working Group has been working on determining how large a problem this is in British Columbia. The group has implemented a strategic approach to prioritize where assessments are done, how to systematically assess structures and finally, how to consistently prioritize which culverts should be fixed first to ensure the greatest habitat returns given limited resources. This ranking exercise is based primarily on

the amount of potential habitat upstream of each culvert. This has been modelled using a Geographic Information System (GIS) and incorporates natural barriers to fish passage, channel gradient, known fish observations, and upstream length. This model continues to be refined with new data inputs each season.

In 2010/2011 a corporate database called the Provincial Stream Crossing Information System or PSCIS was created to house all culvert assessment, design, and remediation data for the province. This is the first standardized repository for this data and it ensures that all the information relating to this type of work is available in one location and can be viewed through iMapBC. This will allow informed decision-making surrounding the prioritization of remediation efforts.

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Mount, C., S. Norris, R. Thompson, and D. Tesch. 2011. GIS modeling of fish habitat and road crossings for the prioritization of culvert assessment and remediation. Streamline Watershed Management Bulletin 14(2): art2. http://www.forrex.org/sites/default/files/publications/articles/Streamline_Vol14_No2_art2.pdf

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14. BC's Forest and Range Effectiveness Evaluation: Water Quality Effectiveness Evaluation

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Industrial gravel roads are recognized to be a major source of fine sediment that can substantially impact water quality. The Forest and Range Evaluation Program (FREP) (see http://www.for.gov.bc.ca/hfp/frep/), which developed as a result of the *Forest and Range Practices Act* requirement for Effectiveness Evaluations (Figure 1) has invested significant resources to evaluate fine sediment generation from industrial gravel roads.

The Effectiveness Evaluation / FREP program was designed to:

- Determine if forest and range policies and practices are achieving government's objectives;
- Assess the effectiveness of legislation; and,
- Identify continuous improvement opportunities.

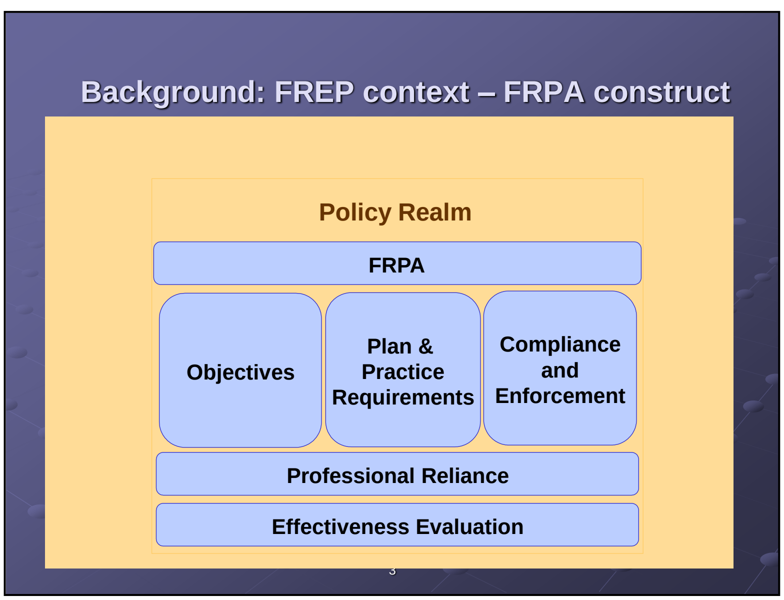

Figure 1.

Water Quality Protocol

The FREP Water Quality Protocol was designed to be:

- Simple
- Quick to execute in the field (20–30 minutes per site)
- Repeatable (two different evaluators working independently will come up with same answer)
- Able to address a wide range of terrain characteristics that occur throughout most forest regions of British Columbia
- Provide recommendations for better management

The Water Quality Effectiveness Evaluation protocol (more information at: http://www.for.gov.bc.ca/hfp/frep/values/water.htm) has been developed for routine or extensive evaluations that can be conducted simply and quickly in the field by non-specialists to provide an accurate snapshot of the effects of forest management on water quality. The methodology requires a rigorous, integrated, step-by-step analysis of three factors at each site in order to evaluate water quality impact. These are:

1. The areal extent of mobile fine sediment surfaces at sites resulting from a forestry or range disturbance;
2. The relative degree to which the surfaces may erode and generate sediment; and,
3. The ability to transport those fine sediments from the site to a stream.

Determining areal extent of a disturbed site is straightforward. All disturbed surfaces draining towards a water body encompass the potential source of sediments from a site. This may include road surfaces, ditches, cutbanks, slope failures, and any other forestry related disturbance features.

To estimate the degree with which the surfaces may erode requires, at a minimum, an estimate of the portion of exposed fine sediment and what level of erosion might be anticipated. Road surfaces present a special case, because of their repeated disturbance by vehicular traffic. A considerable body of research has been conducted on forested lands, including forest roads and the magnitude of sediment generation expected. (Cederholm, Reid and Salo 1980, Sullivan, K.O and S.H Duncan 1980, Reid L.M. 1981, Burroughs, E.R. and J.G King 1989, Luce, Black and Thomas 1999, MacDonald, L.H. and J.D. Stednick 2003, Carson and Younie 2003, and Beaudry 2004).

The Universal Soil Loss Equation was reviewed as a preliminary basis for the assessment of the magnitude of erosion, recognizing its limitations in assessing effects on distinctly non-agricultural surfaces and complications associated with water channeling with ditches, road ruts, culvert outfalls, etc., (Soil Conservation Service 1978). Also reviewed was Washington State's road surface erosion model. (Dube, Meghan, and McCalmon 2004). Useful aspects of that model were incorporated into the Water Quality Effectiveness Evaluation Protocol.

To complete the evaluation, an estimate of connectivity between sediment source and stream was required. The degree of connectivity is obvious when a ditch flows directly into a stream. However in many other instances the partial filtering effects of a forest floor or retaining pond must be taken into consideration.

From these estimations of volumes of sediment generated at a site (Figure 2), Sediment Generation Potential Classes were assigned, based on their relative impact on the stream (Table 1). A consensus of water resource managers familiar with roads and sediment delivery was used as a basis for assigning relative degrees of impact. The rating system has provided the Ministry of Forests, Lands and Natural Resource Operations with an independent assessment of how well licensees are maintaining water quality in a results-based management system. For an explanation of the term "results-based forest management", see:
http://www.for.gov.bc.ca/code/backgrounders/whatis.pdf .

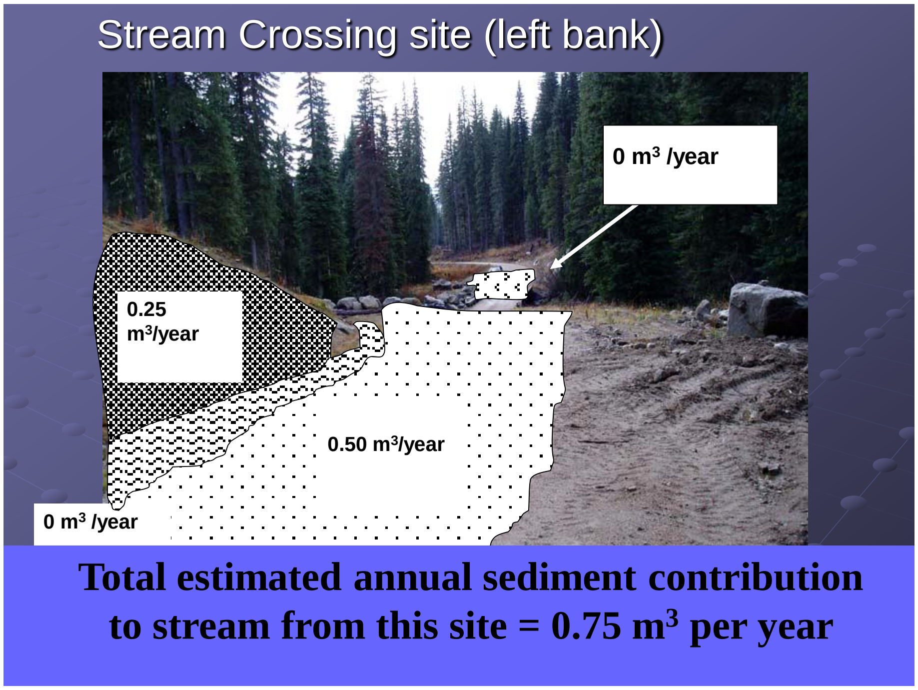

Figure 2. *Within the Water Quality Protocol, areas and rates of surface erosion are assigned to the area of each component within a mini-catchment draining towards a stream. This provides a simple estimate of volume of fine sediment.*

Once a site has been assessed for the amount of sediment being generated it is assigned to an impact class ranging from very low to very high sediment generation potential. Table 1 shows the breakdown of sediment generating classes for the water quality index calculated using the Water Quality Protocol.

Table 1. *Rating of total fine sediment generation from site.*

Total Volume of Fine Sediment Generated (WQ Index)	Site Sediment Generation Potential Classes
< 0.2(m^3)	Very Low
0.2 - 1 (m^3)	Low
1 - 5 (m^3)	Moderate
5 - 20 (m^3)	High
> 20 (m^3)	Very High

Those sites assigned to a moderate or higher sediment generation potential require a further evaluation of management practices that might be used to reduce the sediment load.

Assessment of results to date (2008–2011)

Over the last four years 3,423 sites have been assessed throughout British Columbia to provide a baseline of data showing forestry impacts on water quality. Figure 4 provides the breakdown of classes for all sites evaluated to-date.

- A Very Low (Green) rating indicates that no action is required;
- Moderate (yellow) rating indicates that some concerns are noted and
- High or Very High (orange and red), indicate that major water impact problems exist at the site level.

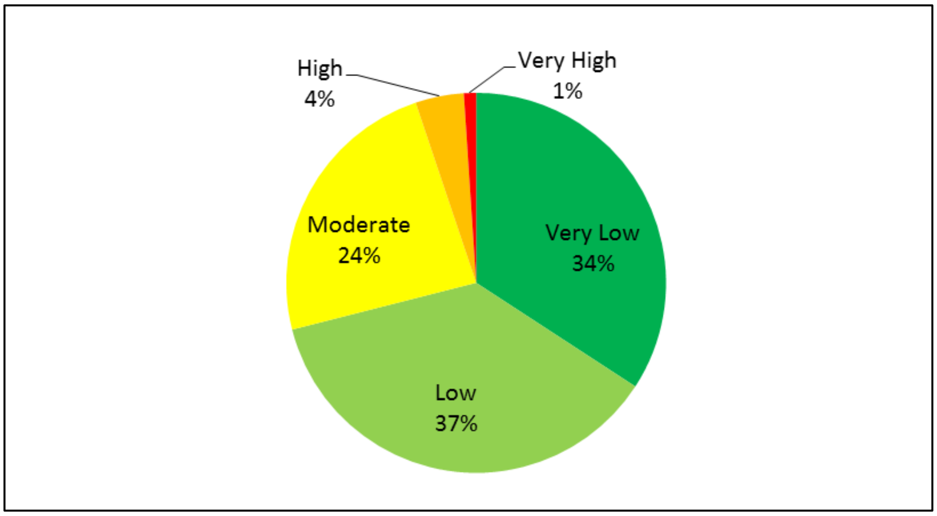

Figure 3. *Provincial water quality impact rating (2008–2011) at 3,423 sites.*

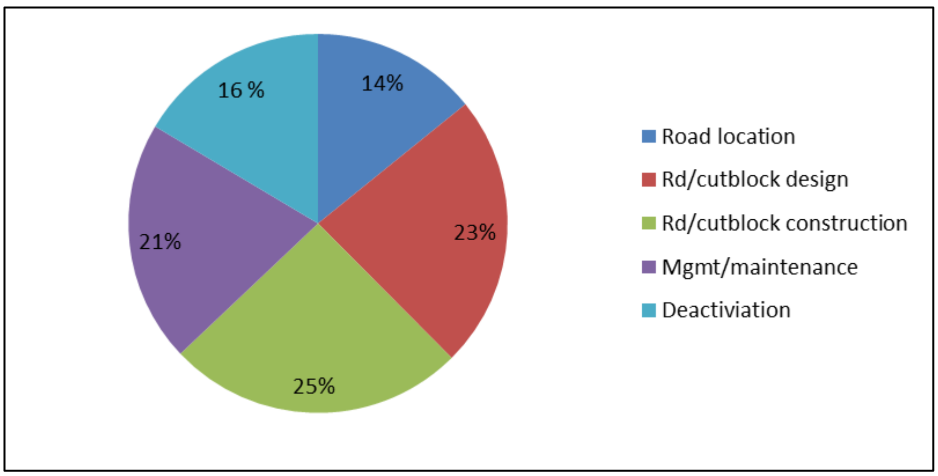

Figure 4. *Challenges by management activity in British Columbia (% of 1,478 observations)*

Table 2: *Management options to reduce fine sediment generation based on 1,478 observations.*

Management activity	Option for improvement	% of observations
Location of road	Seek alternate alignment	11
	Avoid steep, unstable slopes	1
	Avoid long gradients approaching streams	2
	Sub-total	**14**
Design of road/ cutblock	Avoid deep ditches close to streams	4
	Increase number of culverts	16
	Place bridge deck higher than road surface	3
	Narrow road and follow natural breaks	0
	Ensure riparian zone is wind firm	0
	Sub-total	**23**
Construction/Harvesting	Minimize soil disturbance	17
	Armour, seed and protect bare soil	1
	Avoid wet areas or use brush mat	0
	Use better quality materials	4
	Armour areas of concentrated flow	2
	Construct sediment trap	1
	Sub-total	**25**
Road Maintenance	Use good quality materials and crown road	7
	Remove berms	10
	Avoid road use when wet or thawing	2
	Restrict traffic	0
	Fall away, yard away from stream	1
	Improve range management	1
	Sub-total	**21**
Deactivation	Use cross ditches, kick-outs, etc.	14
	Pull back unstable materials	1
	Pull culverts and armour crossing	1
	Sub-total	**16**
	Total	**100**

Future updates and improvements

A. Importance of stream discharge

The Water Quality Effectiveness Evaluation protocol provides a means to prioritize the degree of potential water quality degradation from disturbed sites. This is its primary goal. With enough sites evaluated within a watershed, the outcome provides the ideal base to assess cumulative impacts on a watershed. The greater the volume of fine sediment entering any drainage (regardless of its size), within the watershed, the greater the cumulative impact (Figure 5). There is an important caveat. Without reference to duration of sediment event, stream size, background turbidity, and specific consequences, no absolute magnitude of environmental impact can be ascribed to a specific stream for a given volume of sediment generated.

Streams naturally have variability in water quantity and quality:

- Geographically;
- Seasonally, and
- As a result of different precipitation events.

A given volume of fine sediment introduced to different streams will have different consequences.

Figure 5.

In more intensive evaluations, such as might be required in Community Watersheds or Fish Sensitive streams, the watershed manager, fisheries expert, or water purveyor may be specifically interested in the direct impact of a particular event on water quality immediately downstream from an evaluated site. This would require revisiting each of the assumptions that were made in the development of the Water Quality Effectiveness Evaluation protocol. For any stream, the shorter the time period for sediment delivery, and the lower the volume of sediment, the better for resultant water quality in that stream. Valuable fish habitat or drinking water intakes located immediately downstream from evaluation sites are particularly sensitive and vulnerable. Small sediment additions, rapidly introduced into very small streams, can cause significant elevation of turbidity levels that may be of concern to water managers. Conversely, large volumes of sediment generated over a long period may, individually, not have serious consequences for larger river systems flowing on landscapes with a high rate of natural erosion and few identified downstream values (Figure 6). The significance of these characteristics to evaluating water quality impacts are discussed below.

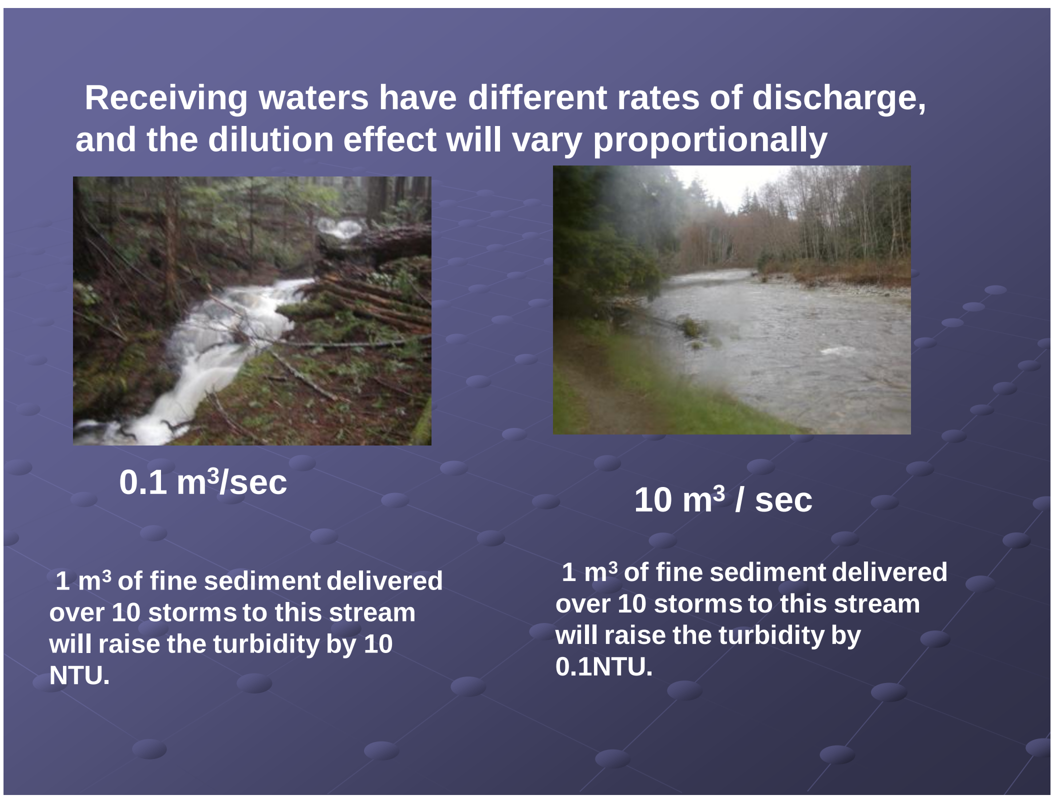

Figure 6

B. Fine sediment effects on fish health and survival

Newcombe (2001 and 2003) came up with turbidity, magnitude, and duration thresholds on fish using an extensive literature search (Table 3). Such analysis is fraught with complications (season, temperature, type of suspended particle, stage of fish's life cycle, dissolved O_2 in water etc.) and as a result must be considered with caution. Table 4 indicates that the sensitive fish can tolerate up to 40 NTU for 10 hours with little or no ill effect whereas if the turbidity rises to more than 2000 NTU over the sample time period, the effects can be lethal.

Table 3: *Turbidity and severity of ill effects (Newcombe 2003).*

Visual clarity of water (*y*BD) and related variables					Duration of exposure to conditions of reduced VISUAL CLARITY ($\log_e$ hours)											Fish reactive distance: *calibrated for trout*		
alternate		*preferred*			0	1	2	3	4	5	6	7	8	9	10			
NTU	*z*SD (m)	BA (m^{-1})	*y*BD (m)		Severity-of-ill-effect Scores (SEV) -- Potential: SEV = $-4.49 + 0.92 (\log_e h) - 2.59 (\log_e yBD)$											ψ_{BD} (cm)	*x*RD (cm)	
				Δ_{15}	Δ_{16}	Δ_{17}	Δ_{18}	Δ_{19}	Δ_{20}	Δ_{21}	Δ_{22}	Δ_{23}	Δ_{24}	Δ_{25}				
1100	0.01	500	0.010	Δ_{14}	7	8	9	10	11	12	13	14				1	-	O
			0.014	Δ_{13}	7	7	8	9	10	11	12	13	14			1	-	N
400	0.03	225	0.02	Δ_{12}	$_P6^{\pi}$	7	7	8	9	10	11	12	13	14		2	-	M
			0.03	Δ_{11}	4	5	6	7	8	9	10	11	12	13	14	3	-	L
150	0.07	100	0.05	Δ_{10}	3	$_P4^{\pi}$	$_P5^{\pi}$	6	7	8	9	10	11	12	13	5	-	K
			0.07	Δ_{9}	2	3	4	5	6	7	8	9	10	11	11	7	-	J
55	0.15	45	0.11	Δ_{8}	$_P1^{\pi}$	2	3	4	5	6	7	8	9	10	10	11	6	I
			0.16	Δ_{7}	0	1	2	3	4	5	6	7	8	9	9	16	17	H
20	0.34	20	0.24	Δ_{6}	0	$_P0^{\pi}$	$_P1^{\pi}$	2	3	4	5	6	7	8	8	24	30	G
			0.36	Δ_{5}	0	0	0	1	2	3	4	5	6	6	7	36	42	F
7	0.77	9	0.55	Δ_{4}	0	$_P0^{\pi}$	0	0	1	2	3	4	4	5	6	55	55	E
			0.77	Δ_{3}	0	$_P0^{\pi}$	$^P0_{\pi}$	0	0	1	2	3	4	4	5	77	66	D
3	1.53	4	1.09	Δ_{2}	0	$_P0^{\pi}$	0	0	0	0	1	2	3	4	5	109	77	C
			1.69	Δ_{1}	0	0	0	0	0	0	0	1	2	2	3	169	90	B
1	3.68	2	2.63		$^P0_{\pi}$	$^P0_{\pi}$	$^P0_{\pi}$	0	0	0	0	0	0	1	2	263	104	A
						Δ_{1}	Δ_{2}	Δ_{3}	Δ_{4}	Δ_{5}	Δ_{6}	Δ_{7}	Δ_{8}	Δ_{9}	Δ_{10}			
					1	3	7	1	2	6	2	7	4	11	30			
					Hours			Days			Weeks		Months					
					a	b	c	d	e	f	g	h	i	j	k			

Figure 1. Impact Assessment Model for Clear Water Fishes Exposed to Conditions of Reduced Water Clarity. A model to estimate severity of impact on rearing success of clear water fish as a function of reduced visual clarity of water (m) and duration of exposure (h), for juvenile and adult life history phases; includes calibration for reactive distance of trout.

Table 4. *Thresholds of turbidity impact to sensitive fish*

Effect on Sensitive Fish	Sediment duration of 10 hours	Sediment duration of 100 hours
Nil to Minor	<40 NTU	<15 NTU
Minor Phyisiological stress	40–500 NTU	15–150 NTU
Moderate to severe Physiological stress	500–2000 NTU	150–500 NTU
Lethal	>2000 NTU	>500 NTU

Using the outcome of the Water Quality Effectiveness Evaluation analysis with a measure of volume of sediment produced provided to streams of varied discharge, the level of elevated turbidity is provided for 100 hour sediment duration on Table 5. It is apparent that at low levels of sediment addition, regardless of the size of stream, the impact on fish is nil or temporary at best. For this reason we have used an increase of 10 NTU as a cut off to indicate no lasting effect on fish populations. Note that this is still a work in progress. As more data becomes available, refinements to these tables are expected.

Table 5. *Effect on fish for different size streams with given fine sediment delivery*

Volume of fine textured sediment delivered to stream (m^3)	**Estimated flow rate of receiving stream or river (m^3/s)**	**Calculated increase of turbidity over background levels of receiving stream, over 100 hours**
0.01	0.01	1 NTU over day
0.01	0.1	.1 NTU over day
0.01	1	.01 NTU
0.01	10	nil
0.01	100	nil
0.1	0.01	10 NTU over day
0.1	0.1	1 NTU over day
0.1	1	.1 NTU over day
0.1	10	.01 NTU
0.1	100	nil
1	0.01	100 NTU over day
1	0.1	10 NTU over day
1	1	1 NTU over day
1	10	.1 NTU over day
1	100	.01 NTU
10	.01	1000 NTU
10	0.1	100 NTU over day
10	1	10 NTU over day
10	10	1 NTU over day
10	100	.1 NTU over day
100	0.01	10,000 NTU over day
100	0.1	1000 NTU over day
100	1	100 NTU
100	10	10 NTU over day
100	100	1 NTU over day

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15. The effects of roads on the post-harvest condition of streams, riparian areas, and fish habitats in British Columbia, 1996–2010

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The effects of forest practices on streams, adjacent riparian areas, and fish habitats in British Columbia have been assessed annually since 2005 under the Forest and Range Evaluation Program (FREP). The principal objective of these assessments was to determine whether forest and range riparian practices, including roads, conducted under the Forest Practices Code (1996–2004) and the Forest and Range Practices Act (post 2004) have been effective in maintaining the structural integrity and functions of stream ecosystems over time. To address this question, a multi-agency/academic technical team developed and tested an indicator-based field assessment protocol for use at randomly-selected stream reaches within or adjacent to cutblocks. Provincial government staff have assessed the physical and biological conditions at stream and riparian sites two years or more after harvest with this protocol, which includes a checklist of 15 main indicators posed as questions. Indicators pass with a yes response, or fail with a no. Site assessments vary based on stream morphology and fish use. Between 114–120 measurements, estimates, and observations are required to complete an assessment based on 38–60 specific indicators which support the 15 main questions.

In the 1,916 sites assessed between 2005 and 2011, 38 % were in Properly Functioning Condition (PFC), 29% in PFC with limited impacts (PFC-L), 21% in PFC with intermediate-level impacts(PFC-I), and 12% were Not Properly Functioning (NPF). Although assessments paid close attention to riparian forest practices, roads were identified to be the most frequent main cause of impacts to streams, affecting 68% of all NPF, PFC-L and PFC-I sites combined, and were a secondary impact source in another 8% of sites. These effects mainly concerned the generation and transport of fine sediments from road surfaces, cut-slopes, and ditches.

Roads principally affected the fine sediment indicator which was the only main indicator out of 15 to score more “no” responses than “yes” responses. Fine sediment deposition in streams also impacted other indicators including aquatic invertebrate diversity, and moss abundance and condition. To lesser extent, roads also affected aquatic connectivity, channel bed disturbance, and channel morphology. Road crossings, especially culverts, sometimes impeded the normal movement of water, sediments, organic matter, and fish in streams. Perched or blocked culverts and other crossings sometimes caused sediment or debris accumulations within or immediately upstream of crossings, or down-cutting below them that blocked fish movements upstream. Forty-three percent (70) of 163 culverts encountered during the assessments were perched or at least partially blocked. Roads sometimes isolated off-channel areas from the main stream resulting in impacts to fish access to seasonal shelter and rearing habitats.

FREP monitoring has shown both positive results and areas for potential improvement. Successful stream and riparian management is associated with a number of basic management actions and outcomes. Important ones include the use of streamside buffers, proper road location and crossing design, and minimizing fine sediment delivery to channels from roads and stream crossings throughout the entire road life cycle.

Background and protocol development

From 2005 to 2011, provincial government field staff assessed a total of 1,916 stream reaches located within or adjacent to randomly selected cutblocks (harvest areas) to determine stream and riparian conditions usually 2 years or more following forest harvest. The objective of these assessments conducted under the Forest and Range Evaluation program (FREP) was to determine whether forest and range practices had been effective in maintaining the structural integrity and ecological functions of stream reaches and associated riparian areas. Post-harvest conditions or "health" of the stream-riparian sites were categorized in terms of "properly functioning condition" (PFC).

Properly functioning condition is defined as streams and adjacent riparian areas that:

1. withstand normal peak flood events without experiencing accelerated soil loss, channel movement, or bank movement;
2. filter runoff;
3. store and safely release water;
4. maintain the connectivity of fish habitats in streams and riparian areas so that these habitats are not lost or isolated as a result of management activity;
5. maintain an adequate riparian root network or large woody debris (LWD) supply; and,
6. provide shade and reduce bank microclimate change.

Streams are considered to be in a properly functioning condition if the impacts of forest development on a set of stream channel and riparian area health indicators are:

- small on average;
- within the range of natural variability; or
- beyond the range of natural variability in no more than a small portion of the stream and riparian habitat.

To determine the post-harvest condition of stream-riparian systems in a large scale, operational monitoring program, an indicator-based assessment protocol was developed and field tested between 2003 and 2005 by an interagency technical team consisting of scientists and specialists from the British Columbia provincial government, the federal Department of Fisheries and Oceans, academia, and the consulting community (Tschaplinski 2010, 2011). The field protocol was provided with supporting reference materials to guide the user and to assist in training field staff (Tripp et al. 2009a, b).

The protocol developed for Resource Stewardship Monitoring (RSM) is a blend of the concepts of proper functioning condition developed by the United States Department of the Interior, Bureau of Land Management (BLM; Prichard et al. 1994, 1998), the “Montana PFC Method” (Hansen et al. 1995, 2000) as modified by the British Columbia Forest Practices Board (2002), and a checklist approach developed by the project technical team specifically to assess the condition of riparian areas, streams, and fish habitats as accurately and rapidly as possible under FREP (see Tschaplinski 2010). This amalgamation of methodologies was intended to take advantage of the best features of each approach. The “Montana Method” is a system for estimating and scoring attributes and factors contributing to the “functioning condition” of aquatic environments such as streams and their adjacent riparian areas co-developed by the Riparian and Wetlands Research Program (RWRP) at the University of Montana and the U.S. Bureau of Land Management (Hansen et al. 2000). This method has also been adapted by the Province of Alberta (Cows and Fish Program), field-tested in British Columbia (Forest Practices Board 2002), and used in modified form by the British Columbia Forest Practices Board to examine the effects of cattle grazing in riparian areas adjacent to 204 streams and 187 wetland and lake sites in four forest districts of the Southern Interior Forest Region (Forest Practices Board 2002).

Because regional or local control or “reference” stream reaches were not initially available when the FREP RSM surveys were due to be implemented, the project technical team developed indicators with threshold values with the intent of covering the range of natural variation. Thresholds used for all indicators of acceptable stream and riparian conditions represent 75–95% of the values typically recorded on streams undisturbed by humans. The assessment, by design, avoided comparing streams to an "average" or "ideal" undisturbed condition. Indicator thresholds came from the scientific literature, a large base of research data collected from five physiographic regions and 10 major forested biogeoclimatic zones in British Columbia, and expert opinion to address data gaps (Tschaplinski 2010). The range of natural variation for pre-harvest or pre-disturbance baseline conditions was identified from the data collected in multi-decade research projects on more than 100 streams where pre-harvest reference conditions were identified and compared to post-harvest changes. As a result, reference conditions were built into the assessment system so that alterations attributed to either forestry practices or other causes including natural disturbances could be identified.

The RSM protocol ultimately included a field checklist of 15 questions, each covering a principal or over-arching indicator of stream and riparian area conditions. Stream indicators included channel bed disturbance; channel bank disturbance; LWD characteristics; channel morphology; aquatic connectivity; fish cover diversity; moss abundance and condition; fine sediments (i.e., sand and finer materials); and aquatic invertebrate diversity. Riparian area indicators included windthrow frequency; soil disturbance and bare ground; LWD supply and root network; shade and bank microclimate; plants that increased disturbance, noxious weeds, and invasive plants; and vegetation, form, vigour, and recruitment (Table 1).

Table 1. *The Resource Stewardship Monitoring (RSM) indicators developed for riparian, stream, and fish habitat condition assessments under FREP.*

Channel bed disturbance	Aquatic invertebrate diversity
Channel bank disturbance	Windthrow frequency
Large Woody Debris characteristics	Riparian soil disturbance/bare ground
Channel morphology	LWD supply/root network
Aquatic connectivity	Shade and microclimate
Fish cover diversity	Disturbance-increaser plants, noxious weeds, and invasive plants
Moss abundance and condition	Vegetation form, vigour, and structure
Fine sediments	

Depending on channel morphology type, substrate conditions, and fish use, 114–120 measurements, estimates, and observations were required to complete a stream-riparian assessment based on 38–60 specific indicators that covered the 11–15 main checklist questions. Each assessment included measurements of channel width, depth, and gradient as well as vegetation retention in the riparian management area (RMA). The riparian assessment required a "yes" (pass), "no" (fail), or "not applicable" (NA) response to each of the 15 main questions. For most streams, nine of 15 questions required multiple "no" responses to a specific indicator before the question could also be answered "no". Each stream was deemed to be in one of four possible outcomes based on the number of "no" responses to the 15 evaluation questions:

- properly functioning condition, or PFC (0–2 "no" responses);
- properly functioning with limited impacts, or PFC-L (3–4 "no" responses);
- properly functioning with impacts, or PFC-I (i.e., intermediate-level effects; 5–6 "no" responses); and
- not properly functioning, or NPF (> 6 "no" responses).

Cutblock and site selection

Each year prior to the field survey season, cutblocks and streams were selected randomly for assessment by a formal protocol which employed the provincial "RESULTS" (Reporting Silviculture Updates and Land Status Tracking System) database. To be eligible for assessment, cutblock had to be minimally 2 ha in area and harvested under the full provisions of either the Forest Practices Code or *Forest and Range Practices Act*. From 2005–2008, cutblocks were limited to those harvested at the stream reach in question at least two years prior to the year of assessment to ensure all streams associated with the blocks were exposed to at least two years of post-harvest environmental conditions (e.g., storms). After 2008, cutblocks and streams were eligible to be sampled after just one year post-harvest.

Streams were eligible for sampling if they could potentially be affected by forestry practices associated with a cutblock. This included streams where one or more component reaches (lengths of channel having similar morphology, dimension (width), and gradient) flowed either through a cutblock or adjacent to it. The criterion for adjacency was defined as any stream reach that occurred within two riparian management area widths of the cutblock boundary for a minimum stream length equal to 30 channel widths (Tripp at al. 2009). Streams adjacent to cutblocks were included in the eligible population because it is rare for larger streams (riparian classes S1 – S3 and S5) to flow through cutblocks. These streams are usually excluded from the area covered by a cutblock.

Stream reaches (longitudinal segments) were the actual sites sampled in the field. Ideally, all stream reaches within or adjacent to the randomly selected blocks were to be sampled. However, if all of the eligible stream reaches could not be sampled due to their great number, they were sub-sampled by a process of stratified random selection. Samples were stratified by riparian class. If time permitted, one stream was selected randomly from within each riparian class. Priority was also given to selecting fish-bearing streams from the largest to the smallest (i.e., classes S1, S2, S3, and S4) in descending order, and then selecting non-fish-bearing streams (class S5 and the abundant class S6) in the same manner. Non-fish-bearing reaches were further sub-sampled by giving priority to the reaches that were closest (i.e., direct tributaries) to fish-bearing streams or other water bodies with fish. Priority was assigned to streams on the basis of their size and fish-bearing status because:

1. The FREP assessments are focused on the "fish" value, and
2. The small, non-fish-bearing class S6 streams are so abundant across all landscapes that it was unlikely they would be inadequately represented.

Field protocol

The field methodology used for the assessment of riparian management effectiveness was as detailed in the protocol for evaluating the condition of streams and riparian management areas published annually in different versions from 2005 to 2009 (Tripp et al. 2005, 2006, 2008, 2009a). The current version (Version 5.0, March 2009) is posted on the FREP web site at:
http://www.for.gov.bc.ca/ftp/hfp/external/!publish/frep/indicators/Indicators-Riparian-Protocol-2009.pdf

Once crews arrived at the cutblocks, the stream sites previously selected in the office by reviewing site-level plans were validated. Reasons for rejecting a stream or a representative reach for assessment might include safety, failure of the watercourse to meet adjacency criteria, or failure of the watercourse to meet the criteria for a valid, classifiable stream according to the definitions under the FPC (BC Ministry of Forests and BC Ministry of Environment 1995, 1998) or by the FRPA which has superseded the FPC (e.g., continuous channel bed for 100 m or more). A site was qualified for assessment if 100 m of stream length, or a length equivalent to a minimum of 30 channel widths, whichever was longer, was available for assessment. Crews might discover that streams drawn on a site-plan map did not exist in the field because of the absence of one or more morphological characteristics such as the presence of a channel bed of sufficient length. If a stream reach initially identified for sampling was rejected in the field, another stream (if available) would be selected by following our protocol (see Cutblock and Site Selection). If no other streams were present at the cutblock in question, no field assessment was conducted.

Whenever a road crossing occurred within the stream reach to be assessed, the effect of the road and its crossing on the stream-riparian system were assessed by anchoring the upstream portion of the stream reach upstream of the crossing site in order to incorporate the crossing right-of-way within the study site and to be able to compare channel bed texture and features upstream of the crossing with conditions downstream.

Provincial sample

Between 2005 and 2011, 1,916 stream reaches were sampled province-wide under the RSM program (Table 2). Because streams within or adjacent to cutblocks were sampled randomly, the sample sizes of the different riparian classes of stream were unequal. The most abundant stream classes—the small (low order) tributaries—were encountered and sampled the most frequently. Therefore, class S6 non-fish-bearing headwater tributaries made up the more than 48% of the overall sample followed by the smallest fish-bearing tributaries. Class S4 fish-bearing streams made up and additional 18% of the provincial sample. Together, class S4 and S6 streams made up about two-thirds of all stream reaches assessed. Although the samples of the different classes of stream differed widely, the numbers closely reflected the actual relative abundance of the different stream classes across British Columbia landscapes.

Sites were also grouped into one of three harvest periods based on the year that harvest was completed: Forest Practices Code (1997–2003), Transition (2004–2006) and FRPA forest management eras (Table 2). This division is somewhat arbitrary because both the Transition and FRPA eras as defined here are known to contain many cutblocks and streams harvested according to FPC Forest Development Plans although he FRPA was officially implemented in 2004. In spite of the unclear division among harvest eras, it is considered that sites harvested in 2007 to the present were at least under the full influence of the FRPA forest management regime. The sample of streams managed under full FRPA influence remains relatively small, amounting to approximately 11% of all sites assessed.

Table 2. *Number of stream reaches assessed for post-harvest riparian and stream channel conditions between 2005 and 2011 for each riparian class and overall by Forest Practices Code, Transition, and FRPA eras. Fish habitat conditions were also assessed in the fish-bearing stream classes (S1, S2, S3, and S4).*

Harvest Years (by harvest completion date)	**Riparian Class**						
	Fish-Bearing				**Without Fish**		
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**Total**
FP Code (1997–2003)	3	57	233	215	64	521	1093
Transition (2004–2006)	5	39	118	95	47	303	607
FRPA (2007–2010)	0	11	46	33	22	104	216
ALL	8	107	397	343	133	928	**1,916**

Results

Among 1,916 stream reaches sampled between 2005 and 2011, 88% were in one of the three categories of properly functioning condition and 12% were not properly functioning (Figure 1). Thirty-eight percent were in the top PFC category and 29% were properly functioning with limited impacts (PFC-L). Together, about two-thirds of all sites were in these two top PFC outcomes while another 21% were properly functioning but with an intermediate level of alterations (PFC-I). PFC and PFC-L streams are considered to best meet the riparian management objectives as defined within the regulations of either the Forest Practices Code or FRPA.

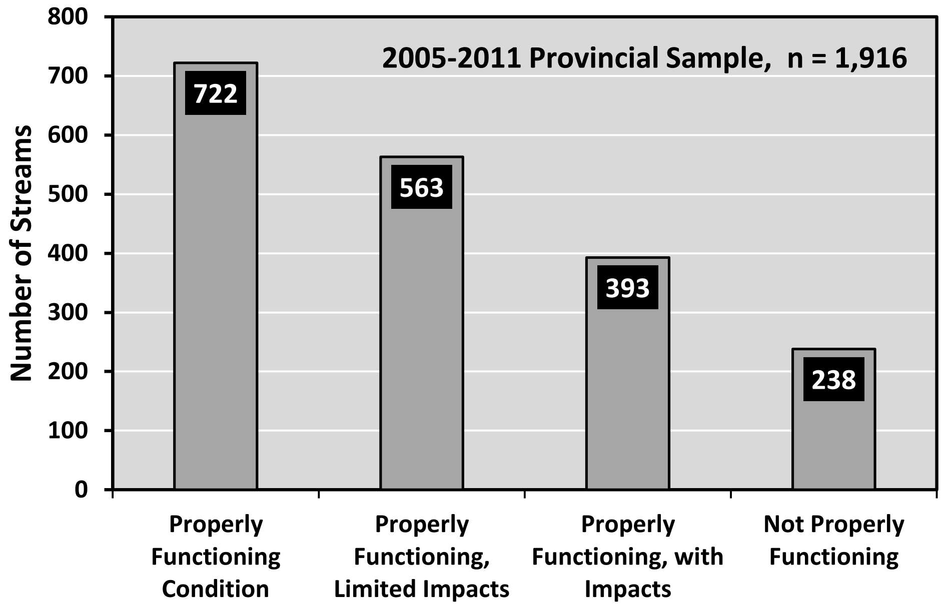

Figure 1. *Province-wide summary of stream-riparian condition assessments conducted in 1,916 sites between 2005 and 2011.*

The same sample examined on the basis of stream class shows that most of the reaches deemed not properly functioning were class S6 non-fish-bearing streams (Figure 2). Nearly 70% of all NPF streams were in class S6 while 17% were in class S4, 4% were in class S5, and 1 % were class S2 streams which are provided with riparian reserves at least 20 m wide (Figure 2). Eighty-two percent of these buffered S3s were in the two top PFC categories combined. Fifty-seven percent of class S6 streams were in the two top properly functioning categories while 43% were PFC-I and NPF combined. Eighteen percent of class S6 streams were NPF. By comparison, 12% of class S4 fish-bearing tributaries were NPF while 67% were in the two top PFC categories.

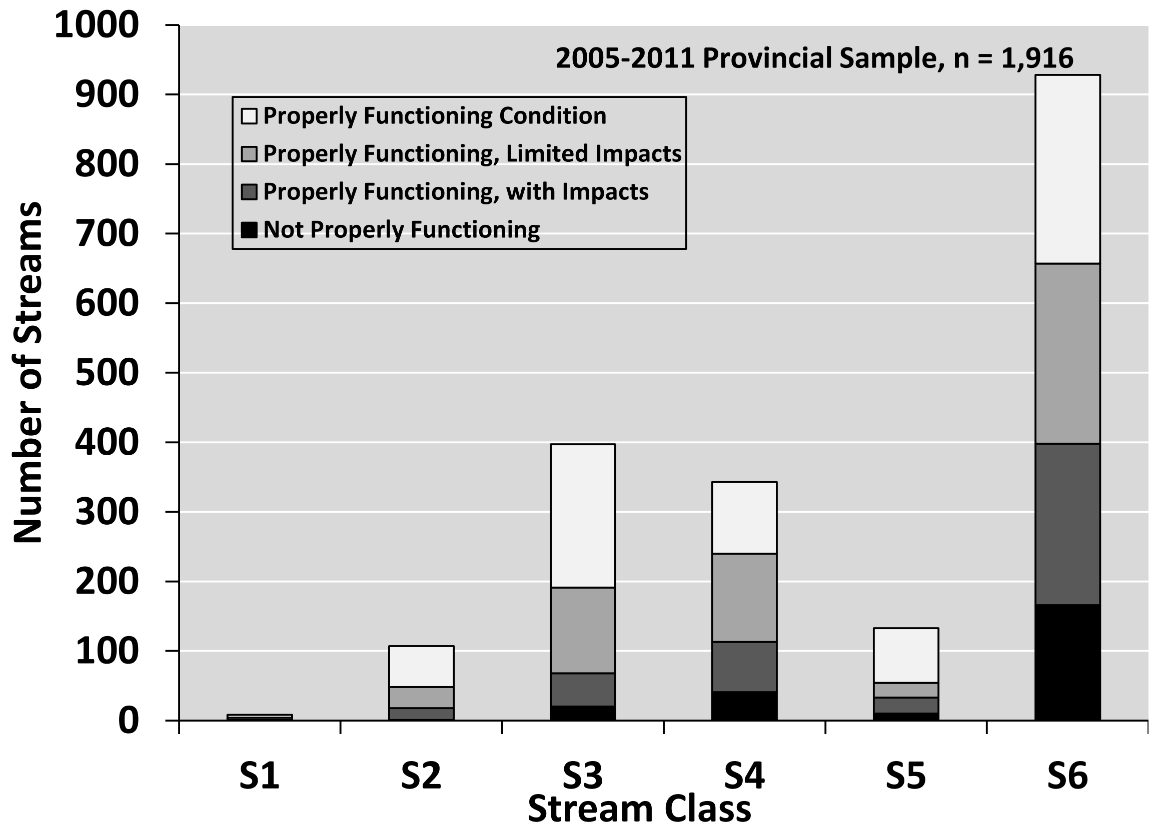

Figure 2. *Province-wide results of stream-riparian condition assessments for the six riparian classes of stream. Of the eight S1 streams assessed, three were in PFC, three were in PFC-L and one was in PFC-I.*

The percentage of streams in all riparian classes that were left not properly functioning after harvest has fallen sharply between pre-FP Code and FPC Code/FRPA eras when riparian management standards were improved and more specifically defined in regulation (Table 3). Prior to the implementation of the Forest Practices Code in 1995–1996, large percentages of streams of all classes were in poor condition. This included 60% of S4 fish bearing tributaries and large percentages of some of the most productive of fish spawning and rearing habitats; that is, more than 40% of class S3 streams and 20% of class S2s (Table 3). Additionally, about 75% of headwater class S6 streams which can influence conditions in fish-bearing habitats downslope were NPF. The percentages of NPF streams reported by the Forest Practices Board in the early Forest Practices Code era are closely comparable to the monitoring outcomes reported by FREP for most stream classes (Table 3).

Table 3. *Comparison of the percent of stream reaches deemed NPF in the pre-FP Code, early FP Code and FREP monitoring eras.*

Riparian Class	**Pre-Code** Percentage Equivalent to FREP NPF Streams	**Early FPC Era** (Forest Practices Board Audit) Percentage Equivalent to FREP NPF Streams	**FREP 2005–2011** Percentage of NPF Streams
S1	5	0	0
S2	20	0.6	0.9
S3	41	4.4	5.0
S4	60	9.4	12.0
S5	45	3.3	7.5
S6	76	20.2	17.9

Trends in post-harvest outcomes for British Columbia streams since the implementation of the Forest Practices Code vary depending upon stream class (Table 4). For the larger fish bearing streams which are provided with riparian reserves, there has been a decline to low percentages of NPF outcomes from the Forest Practices Code era to the FRPA era (Table 4). Conversely, there appears to be an increase in the percentage of NPF streams for both fish-bearing class S4 streams, and non-fish-bearing class S5s (Table 4). Conclusions based on these increases are not yet possible because of the small sample sizes available at this time for FRPA era management (2007–present) for all streams in total (n = 216), and for class S5s in particular (n = 22).

Table 4. *Comparison of the percentage of stream reaches for each riparian stream class deemed NPF by FREP for the Forest Practices Code, Transition, and FRPA management eras defined by year that harvesting was completed.*

	FREP Monitoring by harvest era		
Riparian Class	**FP Code Era 1997–2003 n = 841 Percentage NPF**	**Transition Era 2004–2006 n = 607 Percentage NPF**	**FRPA Era 2007–2010 n = 216 Percentage NPF**
S1	0	0	0
S2	2.0	0	0
S3	6.1	5.9	2.2
S4	9.9	12.6	15.2
S5	7.3	4.2	18.1
S6	17.9	16.5	18.3

When outcomes for the 15 primary indicators are examined individually (Figure 3), it is clear that most indicators scored a pass ("yes" response) more frequently than a fail ("no" response). Furthermore, for a majority of indicators, the yes responses exceed the no responses by a wide margin. The only indicator where no responses due to site-level forestry activities nearly equalled the yes responses was the fine sediments indictor (Figure 3). Also, the indicator for vegetation form, vigour, and structure scored a relatively high number of forestry-related no responses. The latter can be linked to the frequency of clearcutting or low tree retention in streamside areas, but the majority of fine sediment impacts were due to roads.

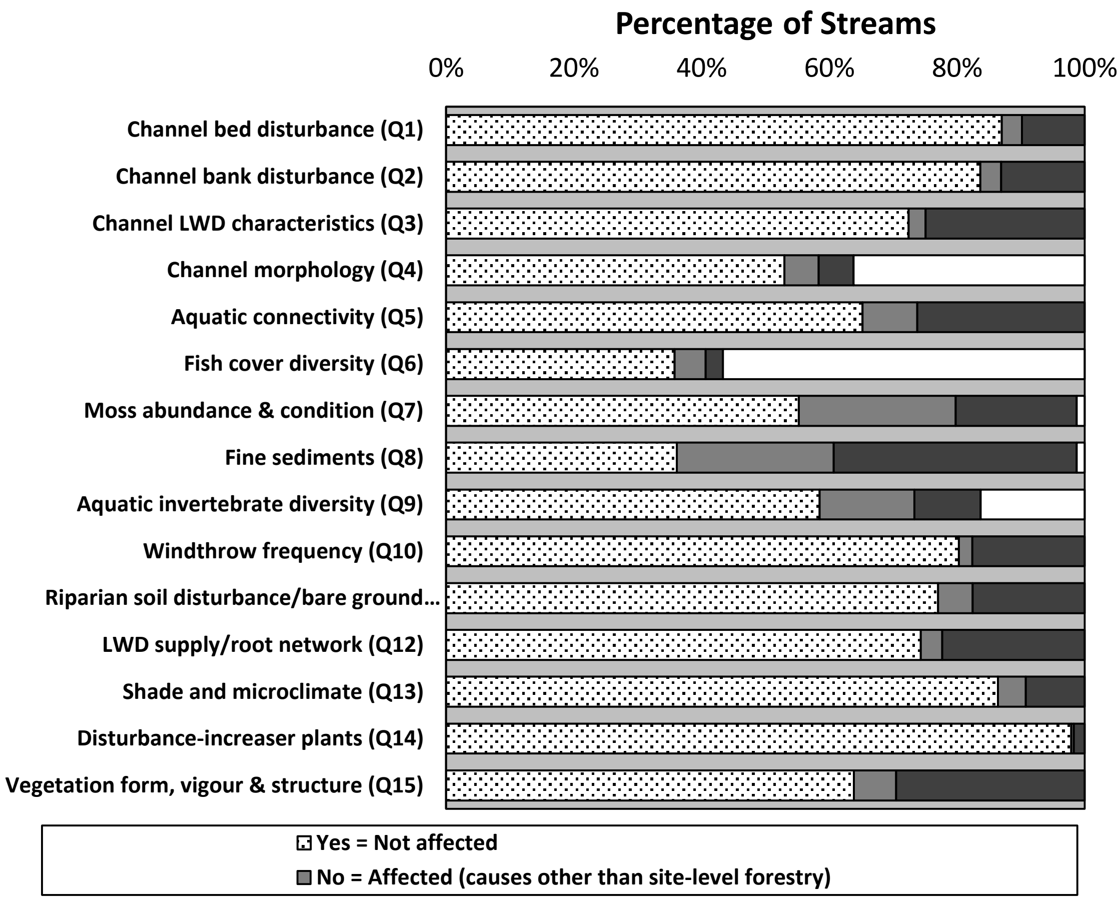

Figure 3. *Frequency (percentage) of yes and no responses to indicator questions for streams assessed by FREP. The "no" responses attributed to site-level forestry practices (cutblocks and roads) are distinguished from the no responses due to other causes such as natural events and impacts originating from upstream and upslope areas. Not applicable (NA) responses occurred for the channel morphology indicator when non-alluvial streams were encountered; when conditions (e.g., elevated stream flows) did not permit some indicators to be assessed; and for the fish cover diversity indicator which was not relevant for non-fish-bearing streams.*

About 38% of all responses to the fine sediments indicator question were attributed to forestry-related activities and structures. Forestry-related fine sediments were therefore widespread and affected all stream classes partly because the dominant source of these materials was from roads and stream crossings (Table 5).

Table 5. *Percentages of sites affected by the 14 most frequently observed impact sources by geographic area. The percentages represent the frequencies that each source was identified as the either a principal or secondary contributor to observed stream-riparian alterations.*

Impact Category	**Coast Area**	**Northern Interior Area**	**Southern Interior Area**	**ALL**
Roads (sediment generation and transport)	**81**	**62**	**65**	**68**
Low RMA Tree Retention	59	43	44	48
Windthrow	23	33	38	32
Falling & Yarding*	53	20	23	30
Fire, Beetle Infestation (non-forestry related)	17	30	40	30
Machine disturbance: Harvesting	20	23	34	26
Livestock Trampling	<1	3	24	9
Perched/Blocked Culvert	3	11	8	8
Crossing Leaks Fines into Stream	4	11	7	8
Livestock Browsing and Grazing**	3	6	12	7
Old Logging	12	3	5	6
Torrents (debris flows in channel)	4	2	2	3
Machine disturbance: Site Preparation	<2	1	3	2
Hillslope failure (landslides)	3	1	<2	2

*Includes logging slash and cut logs in stream; cross stream falling and yarding.
**Wildlife activity in the coast geographic area.

Road-related results

Provincially, two-thirds of all impacted sites were affected by mineral sediments generated and (or) delivered to the stream channel by roads from road surfaces and ditches (Table 5). Sediments delivered by roads in this way were the leading forestry-related impact factor followed by low tree retention in riparian areas (48%), riparian management area (RMA) windthrow (32%), cross-stream and near-stream falling and yarding (30%), and machine disturbance in the RMA during harvest (26%). In the coast geographic area, more than 80% of all impacted sites were affected by road-delivered fine sediments as either a main or secondary impact factor.

Fine sediment deposition in streams also impacted other indicators including aquatic invertebrate diversity and moss abundance and condition. To lesser extent, roads also affected aquatic connectivity, channel bed disturbance, and channel morphology. Road crossings, especially culverts, sometimes impeded the normal movement of water, sediments, organic matter, and fish in streams. Perched or blocked culverts and other crossings sometimes caused sediment or debris accumulations within or immediately upstream of crossings, or down-cutting below them that blocked fish movements upstream. Forty-three percent (70) of 163 culvert crossings encountered during FREP assessments were perched or at least partially blocked. Roads sometimes isolated off-channel areas from the main stream resulting in impacts to fish access to seasonal shelter and rearing habitats.

Roads also affected streams at crossings by fine sediment “leakage” from bridge decks and other crossings (also related to road grading activity). However, both perched or blocked culverts, and fine sediment leakage at crossings each affected about 8% of all impacted sites (Table 5; Figure 4). Therefore, fine sediment delivery from eroding road surfaces by ditch drainage were the dominant mechanisms of road-related effects on streams, and exceeded the frequency of impacts by other road-related sources by 10 fold (Table 5; Figure4).

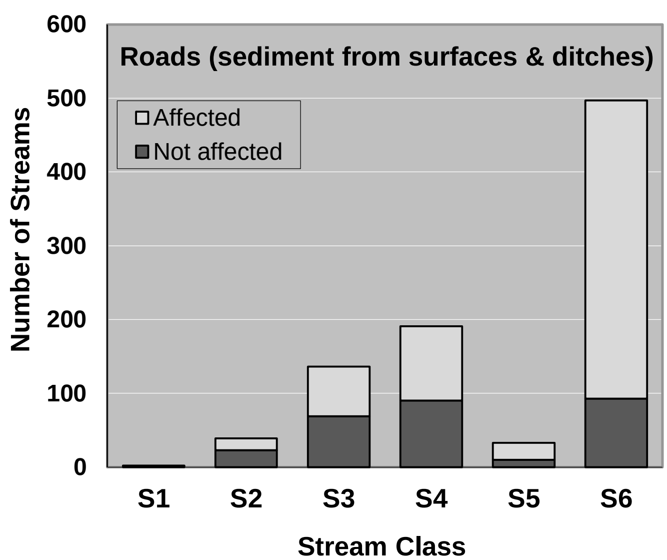

Figure 4a.

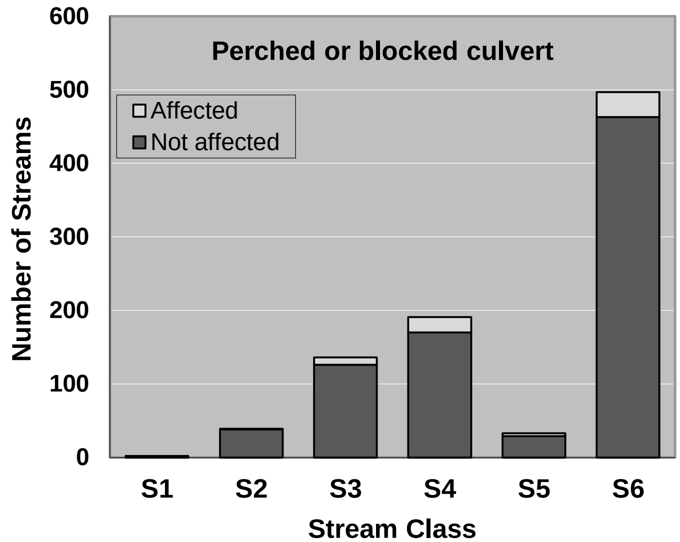

Figure 4b.

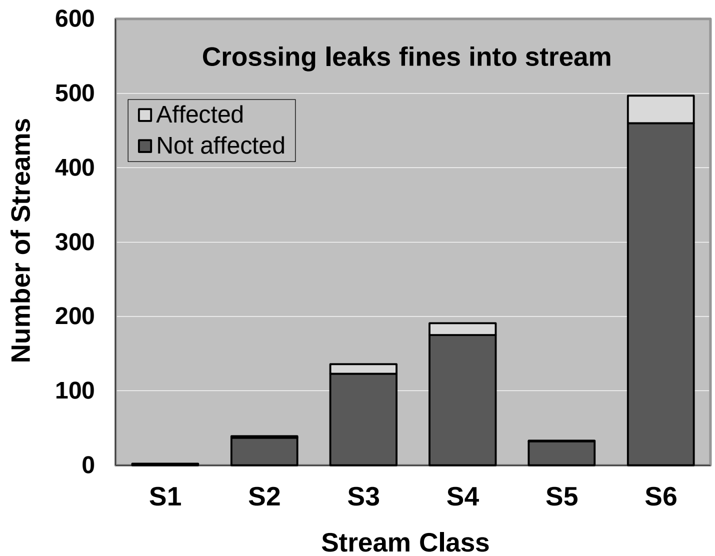

Figure 4c.

Figure 4 a-c. *Frequency of impacts from road related sources. The principal mechanism of impacts to streams from roads is the delivery of fine sediment from road surfaces and ditches. This source of impact affected a large fraction of class S2 to S6 stream classes and exceeded other road-related impact factors by 10 fold.*

Fine sediment impacts from roads also far exceeded the frequency of non-road-related impacts involving mobilization and transport of sediments and (or) debris. Windthrow and machine disturbance due to harvesting in riparian management areas each affected one third the number of streams compared to road-related impacts (Figure5). Trampling by livestock (and/or wildlife) and hillslope failures (e.g., landslides, debris flows) affected yet fewer streams (Figure5).

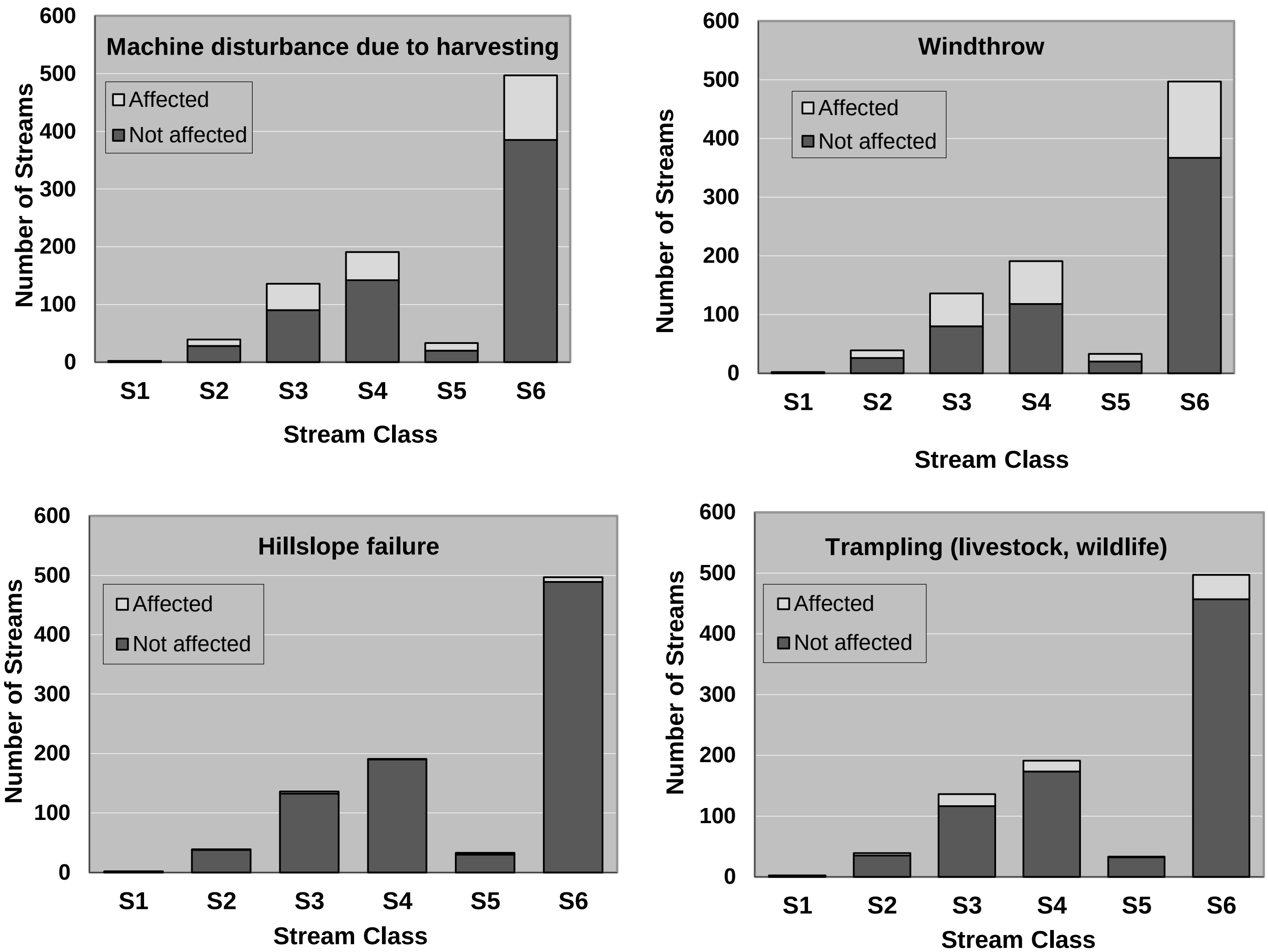

Figure 5*. Frequency of impacts from sediment and organic debris from non-road related sources. These sources of impact affected streams at much lower frequencies than roads. Fine sediment from road surfaces affected more than three times the number of stream reaches than either windthrow or machine disturbance during harvesting in the riparian management area. Hillslope failures and livestock were relatively minor contributors to stream reach alterations on a province-wide basis.*

It is well known that fine sediments from road surfaces and other sources can be transported along ditch lines to enter streams at crossings (Maloney and Carson 2010). The origin of these sediments and the relative amounts delivered (or potentially delivered) to channels from each local source has also been determined for a large sample of sites assessed under FREP with the Water Quality Assessment Protocol (Maloney and Carson 2010).

Practices that can reduce or mitigate these sediment sources and delivery mechanisms are also well known and have been applied for many years (BC Ministry of Forests et al. 1992, BC Ministry of Forests 2002, Maloney and Carson 2010). Nevertheless, fine sediment mobilization and transport to stream channels continues to be a management challenge. Sediment management needs to be considered for the full life cycle of a road from the location and design phase to the construction, maintenance, and deactivation phases (BC Ministry of Forests 2002, Maloney and Carson 2010). Preventing excess sediment mobilization from it source areas is key. One way to achieve this is to minimize soil disturbance in areas connected to the stream channel network. However, regardless of the amount of soil disturbance in managed sites, if sediments have no means to be transported from source areas to streams, there will be no effect on the channels or their aquatic habitats.

Measures to control road-related sediments include:

- proper design of road cuts and fills;
- revegetation of cut-and-fill slopes and other disturbed ground where erosion is a concern;
- proper culvert placement;
- crowning roads;
- use of better quality materials for road surfaces;
- minimizing the length of ditch lines by installing culverts strategically to divert sediment-laden flow before it can reach streams;
- armouring culvert outflows where necessary;
- use of ditch blocks to capture sediment;
- keeping ditches open;
- placing bridge decks above road grades so that water flows away from bridges;
- maintaining roads in a timely manner consistent with road use and risk to the road and drainage network; and,

- deactivating roads when they are no longer needed (BC Ministry of Forests 2002, Maloney and Carson 2010).

Riparian tree retention

Low levels of riparian tree retention were the second only to roads as the most frequently cited source of impact to streams and aquatic habitats (Table 5). However, FREP assessments have shown that there is much more streamside tree retention adjacent to all classes of stream than required in regulation by either the Forest Practices Code or the FRPA (Table 6). For example, class S1, S2, and S3 fish-bearing streams which require no-harvest riparian reserves 50, 30 and 20 m wide respectively, were provided with streamside buffers 67, 42, and 32 m wide (Table 6). The assessed sample of class S1 rivers is too small to be meaningful; nevertheless, all classes of large fish-bearing streams appeared to be managed conservatively.

No-harvest reserves or buffers have never been required in the RMAs of class S4, S5, and S6 streams. Practices and levels of riparian retention can and do vary widely. It has been often assumed that these streams are managed most commonly with clearcut harvest prescriptions for their riparian areas and left with little overstory vegetation (Chatwin et al. 2001). Monitoring by FREP has shown that large percentages of all of these stream classes receive substantial amounts for streamside retention. Nearly 80% of class S4 fish-bearing tributaries are provided with streamside buffers which are 17 m wide on average (Table 6). Class S5 non-fish-bearing streams (streams that are >3 m wide), were provided with buffers 28 m wide on average (2006–2008 sampling years), nearly equivalent to the 30 m wide riparian reserves required for class S2 fish-bearing streams. Perhaps the most unanticipated result was the frequency and amount of streamside retention given to a large proportion of the small, non-fish-bearing class S6 headwater streams—56% of assessed S6 stream reaches were provided with riparian retention that was equivalent on average to buffers 11 m wide.

Table 6. *Frequency of buffer use and average width of no-harvest buffers by stream class. Means are rounded to the nearest whole number and provided with ± standard error. Buffer width was measured from the streambank to the first sign of tree harvest in the RMA or beyond at all sites assessed between 2006 and 2008. A width of 0 m indicates harvest activity to the streambank; however, this does not necessarily mean clearcutting with no trees retained, because different harvest treatments (e.g.; clearcut, partial cut, single-tree selection, etc.) are grouped together.*

Stream class	Percentage of streams buffered	Buffer width (m) = Mean distance from streambank to beginning of tree harvest (harvest edge)		
		Mean	**± Standard error**	**Sample (n)**
S1	100	67	16.9	5
S2	100	42	2.5	72
S3	100	32	1.4	211
S4	78	17	1.4	179
S5	84	28	4.5	76
S6	56	11	1.0	516
ALL	74	20	0.8	1,059

Riparian retention for class S4, S5, and S6 streams was achieved by a variety of strategies that included establishing the boundary of the cutblock fully or partially outside of the riparian management area of these streams. However, some streams that occurred within cutblocks were provided with buffer strips of equal or variable widths on both sides of the channel. In spite of this retention, more than 20% of class S4 streams and 44% of class S6s had their RMAs completely harvested of trees or nearly so. Because these small streams are very abundant across the landscape, these percentages represent a large number of streams left without a treed buffer.

A longstanding riparian management question has been whether acceptable environmental outcomes can be achieved for small streams managed without retaining streamside trees in the form of an unharvested buffer strip or some other pattern of substantial riparian retention (Chatwin et al. 2001). An examination of 1,668 sites assessed between 2006 and 2011 by FREP shows that results for S4, S5, and S6 streams provided only with understory vegetation achieved the top two properly functioning outcomes much less frequently than class S1 to S3 fish-bearing streams provided with riparian reserves (Table 7). Eighty-three percent of class S1 to S3 streams provided with riparian reserves were in the top two properly functioning outcomes, including 55% in PFC (Table 7). Five percent of these streams were not properly functioning. In comparison, 52% of class S4, S5, and S6 streams that received little or no riparian tree retention were in the top two PFC categories including 22% in PFC, while 20% were NPF. However, S4, S5, and S6 streams which received riparian buffers (full tree retention) within at least 10 m of their banks achieved results virtually indistinguishable from those observed in fish-bearing streams given relatively wide riparian reserves: 81% were in the top two PFC categories and the NPF outcomes were reduced compared to small streams with clearcut RMAs by a factor of four to 5% (Table 7). Similarly, the percentage of properly functioning outcomes with intermediate-level impacts (PFC-I) were reduced by one-half from 28 to 14 %.

Table 7. *Functional outcomes of streams managed under three different riparian retention strategies. The percentages of streams in each functional outcome are compared for fish-bearing streams with mandatory riparian reserves (classes S1, S2, and S3 streams), and classes S4, S5, and S6 streams managed either by (1) retaining mainly understory trees or (2) retaining both overstory (dominants and co-dominants) and understory trees within the first 10 m of their RMAs. All retention levels were combined for both overstory and understory trees. The functional outcomes for all streams in the combined 2005–2008 sample are also provided. Sample size, n = 1,668*

Functioning condition	**Percent of Streams**		
	Fish bearing with riparian reserves (Class S1, S2, S3)	**Classes S4, S5, and S6 with overstory and understory retention**	**Classes S4, S5, and S6 with mainly understory retention**
PFC	55	52	22
PFC-L	28	29	30
PFC-I	13	14	28
NPF	5	5	20

Key findings and recommendations for improved management outcomes

The results of FREP monitoring in support of the FRPA fish-riparian values have shown both positive results and areas for improvement. Successful stream and riparian management is associated with five main management actions and outcomes:

1. Management of road-associated generation and transport of fine sediments;
2. Level of RMA tree retention – use of riparian buffers;
3. Windthrow management;
4. Avoiding falling and yarding trees across streams; and,
5. Minimizing harvest-associated machine disturbance in the RMA.

The two leading findings that influenced stream riparian outcomes were:

1. The amount and frequency of road-related fine sediment found at stream crossing for all classes of stream; and,
2. The level of riparian tree retention for class S4, S5, and S6 streams.

The management of fine sediments remains a concern in spite of improvements suggested by trends between the Forest Practices Code harvest years (2007–2003) and FRPA harvest years (2007–2010). For example, the percentage of non-fish-bearing class S6 headwater streams affected by fine sediments fell from 83% in the Code era to 60% in the FRPA era.

The effectiveness of riparian reserves or buffers are clear from the FREP assessments. The functional outcomes or "health" of small streams left with riparian buffers 10 m wide were equivalent to larger fish-bearing streams with riparian reserves 20 - 50 m wide. However, nearly 20 % of class S4 streams, and 45% of S6s, are left with little or no streamside tree retention.

These findings have led to recommendations in the "Assistant Deputy Minister Resource Stewardship Report: Results and recommendations of the Forest and Range Evaluation Program", July 2012, available at: (http://www.for.gov.bc.ca/ftp/hfp/external/!publish/frep/reports/FREP_ADM%20Stewardship%20Report_July2012.pdf).

The ADM report's recommendations were based on practices associated with the most successful fish and riparian resource management outcomes reported by FREP's

Resource Stewardship Monitoring program. The two biggest actions that will enhance riparian outcomes in British Columbia are:

1. Limiting the fine sediment input that results from road crossings and riparian practices by employing long-established best practices; and
2. Providing a 10 m wide treed buffer on S4, S5, and S6 streams following the priority guidance given below.

Best management practices concerning fine sediment delivery to streams and stream crossings have been well established for many years and should be applied for the entire life span of a crossing. Some specific actions have been given above in the Results section. Other details are provided in the actions listed in British Columbia's "Forest and Range Effectiveness Evaluation: Water Quality Effectiveness Evaluation" by David Maloney in this document. These documents are excellent sources of additional information:

Forest Road Engineering Guidebook
http://www.for.gov.bc.ca/tasb/legsregs/FPC/FPCguide/Road/FRE.pdf

Erosion and Sediment Control Practices for Forest Roads and Stream Crossings
http://www.feric.ca/en/?OBJECTID=D1719534-C09F-3A58-EAFC64F9625A170F

Fish-stream Crossing Guidebook
http://www.for.gov.bc.ca/hfp/Fish/Fish-Stream%20Crossing%20Web.pdf

The Resource Stewardship Monitoring assessments have shown that much more riparian retention has been applied province-wide for all stream classes than is required by regulation, including class S4, S5, and S6 streams. Without further increasing riparian retention levels within a watershed or a landscape, this existing level of retention could be distributed where the greatest benefits for fish and aquatic values would be achieved with minimum additional cost. Therefore, the ADM report recommends retention for the following priorities:

1. Placing 10 m wide riparian buffers on all S4 streams and perennial S5 and S6 streams that deliver water, alluvial sediments, organic materials, nutrients, invertebrates and (or) large woody debris downstream to fish-bearing areas and (or) drinking water sources.

2. Retaining, at a minimum, all non-merchantable trees and smaller vegetation and as many other wind-firm trees as possible within the first 10 m from the stream bank on intermittent and ephemeral S5 and S6 streams that are directly connected to fish-bearing areas and (or) drinking water sources.

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16. The West Okanagan–Nicola Pilot Cumulative Impacts Project

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Doug Lewis was unable to attend the workshop but kindly sent along his PowerPoint presentation. Our Master of Ceremonies Patrick Daigle used Doug's speaker notes to present the talk.

"Cumulative effects are the net effects that a resource experiences from the combined influences of multiple management practices or influences in combination with natural disturbances distributed through space or time, or both"

– Reid, 2010

Understanding and Evaluating Cumulative Watershed Impacts

http://treesearch.fs.fed.us/pubs/34319

This definition implies that the cumulative effects are greater than the accumulated effects or simple sum of effects because interactions between effects are involved. There are also different perspectives on cumulative effects that need to be considered.

We traditionally think of cumulative effects as being effects on the environment but cumulative effects also impact those with existing tenures or cultural rights, so the socio-economic and cultural aspect of cumulative effects must also be considered.

Recent literature on cumulative effects has indicated that it is not so much a problem of lack of science and knowledge, but it is a problem manifested through primarily policy and legislation.

For example, in British Columbia recent growth in several non-forestry resource sectors has resulted in many overlapping tenures competing for the same resources. This overlap is due to the way government has historically allocated tenures, with different agencies granting tenure rights, often without full understanding of other activities on the landbase within that sector or between sectors. As an example, in the West Okanagan–Nicola Cumulative Effects Demonstration Project, we looked at a 345,000 ha landscape and found 440% of that area was under some sort of permit or tenure, a result that was found to be similar through the whole Thompson–Okanagan region. While many of these tenures are not exclusive the potential for interacting effects greatly increases with this type of overlap.

Overlapping tenures becomes problematic once tenure holders try to exercise those rights which may result in unintended consequences to one another and/or the environment. Unintended consequences may materialize because different ministries authorize permits and applications often without fully considering implications on other sectors. Likewise, where assessments do exist, decisions are often informed by project or sector specific assessments that only consider the incremental effects of the specific project or application. Assessing impacts from overlapping developments is further complicated due to a lack of specific, measurable objectives for values, and different regulatory limits and standards that do not apply equally across resource sectors.

The province of British Columbia currently has several initiatives underway to help overcome these challenges:

- Changes in the provincial government's structure to amalgamate ministries and decision-making towards a "One Land Manager" and "One Process" approach for dealing with project applications and permits;
- The development of an *Integrated Decision-Making Act* (IDM Act) to overhaul the regulatory framework to enable grouping decisions into one agency, under one legislative authority;
- Setting consistent objectives for values on the landscape, such that all sectors will be required to follow the same set of rules;
- The Cumulative Effects Assessment Framework (CEAF) to address the issue of project and sector specific assessments; and

The Cumulative Effects Assessment Framework

The following diagram is used to conceptually illustrate the Cumulative Effects Assessment Framework (CEA Framework). The CEA Framework does not define which values are important to society (top grey box). Values are defined through existing processes such as land use plans or identified in current legislation to be considered in assessment and monitoring.

The CEA Framework also does not make decisions (bottom grey oval). This task is left to statutory decision-makers within government.

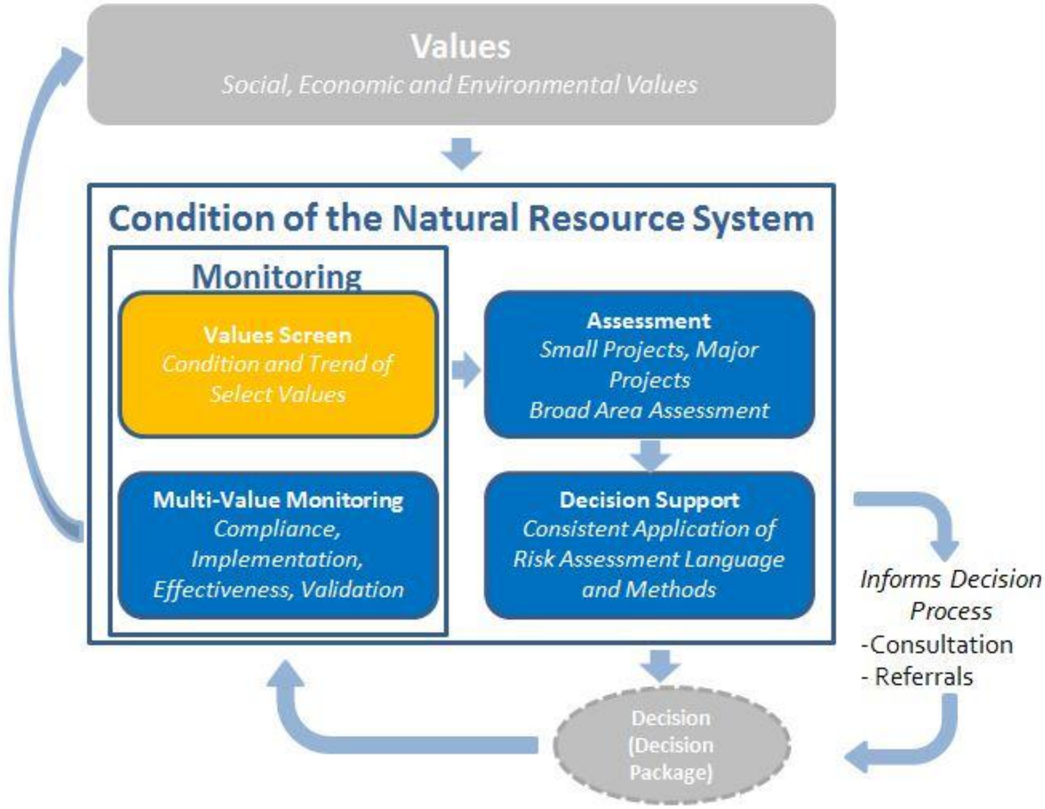

Figure 1: *The Cumulative Effects Assessment Framework.*

Instead the CEA Framework consists of monitoring, assessment, and decision support pieces which can assist in improving our understanding of the condition of the natural resource system and how likely this is to maintain the values society has identified as important. In this way it can inform the decision process to assist us in making better decisions on how to manage our effects on the landbase, towards achieving our objectives for values. The cumulative effects pilots are working through each of the components of the framework to demonstrate concepts, and test and produce operational tools and methods that are intended to be implemented across regions.

The Values Screen of the Cumulative Effects Assessment Framework

In the past government has made GIS-based datasets publicly available for a number of resources such as forest cover, species distribution mapping, infrastructure, legal boundaries, etc.

The challenge is that resource practitioners must continually pull these datasets together, then update, re-analyse, and interpret what they mean to a value or concern on the landbase, and report out. In few circumstances are analyses done consistently, and they have to be done repeatedly to support individual decisions, often at great cost in time and resources to government staff and proponents.

By transitioning to the Values Screen we can prevent these issues by providing a consistent GIS data layer that uses and applies existing science and expert knowledge to interpret and develop new information layers that include:

- The known spatial location and extent of values on the landbase;
- The level of risk associated with maintaining a value-based on current condition; and,
- The condition of the value within the context of socially defined objectives, legal regulations, or non-statutory guidance.

Values screen—Strategic shifts

The development of the Values Screen supports several strategic shifts away from how information is currently made available and used to assess the implications of land use activities, to a place that makes this information much more available to support cumulative effects assessment.

Figure 2. *Strategic shifts enabled by the Values Screen.*

The first key strategic shift is one from where existing information in multiple datasets must be compiled and analysed to assess the condition of a value, to one where the analysis and interpretations are consistent and there is a transparent approach to the analysis, with assumptions and uncertainties clearly documented. This shift provides a common starting point for proponents and professionals outside and inside government to understand the condition of a value. It does not mean that analysis is final as new information can improve assessments or reduce uncertainty.

The second strategic shift is a move from inconsistent data sets or areas with data gaps to one where custodians within government are responsible for ensuring data gaps are filled. Data gaps, missing data, or uncertainties due to unreliable or poor information are dealt with through inventory and research. Custodians will ensure datasets needed to update values screen information are complete. They will regularly update and publish the information so it is publicly available.

The third strategic shift revolves around efficiency. Proponents and government alike will no longer have to compile, analyze, and interpret "one-offs" for each application referral or decision. Instead, information on current condition with respect to the value and meeting existing objectives, is readily available. This information would also include a knowledge summary— a document that clearly outlines: what the value is; factors that affect its condition; methods and/or data sources and assumptions used to assess condition; and management actions that are triggered.

Values Screen information is intended to inform decision-making regarding project applications and permits by providing an initial assessment of risk to that value based on current condition. This initial assessment would be completed using Values Screen information and with an understanding of existing mitigation such as existing regulations or best management practices that may already be in place to control risk.

This assessment can be used by a decision-maker to trigger:

- A more detailed project based impact or cumulative effect assessment to reduce uncertainties or confirm or deny hazards or consequences associated with a project application;
- Where additional risk control may be required to ensure any authorized activities are within the acceptable or tolerable level of risk, such as mitigation options available through application of the environmental mitigation policy;
- Where additional effectiveness, implementation, or compliance monitoring may be required to ensure a project is meeting intended outcomes for values and remains within an acceptable level of risk.

Road information informs the condition of values

The state of current GIS-based information in developing the Values Screen is a key factor. Road information is critical in assessing effects of land use activities on many values. Much of our existing road information provides information on the spatial location, type of road, permit status, or permit holder information. This information can be used to derive a number of metrics, such as road density, which in turn can be used to inform a number of both positive and negative road-related values we are concerned about.

For example, roads provide access for humans that can increase mortality, harassment, or disturbance to some wildlife. However, this access also contributes to human well-being by providing hunting opportunities for subsistence and recreational value or off-road vehicle use for recreational and tourism use.

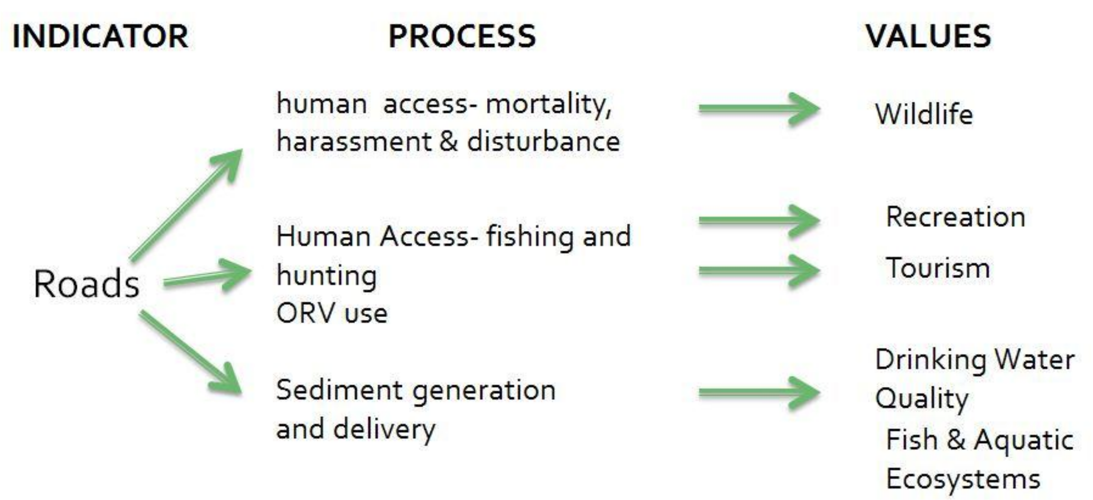

Figure 3. *Road data informs conditions of values.*

The density of roads and their locations relative to streams can also inform of us of the potential for impacts to water quality from sediment inputs and where this may pose a risk to water used for drinking or to fish and aquatic ecosystems sensitive to increased sediment.

Unfortunately our road inventories often don’t contain specific road information such as road construction and maintenance detail, nor do we have reliable information on the intensity of use by different resource users or recreational users. So to use road information we are required to make assumptions regarding condition and use, knowing that factors such as construction standards, roadbed material, or maintenance schedules can affect the amount of sediment generated. In other circumstances, the use of gates to restrict access, the level of deactivation, or growth of vegetation on the roads can significantly impede access and assumptions must be made to account for these factors when using road inventory data. This type of information must be obtained through field-based monitoring or more detailed assessments at the site level, and would improve certainty in the analysis results or cause the results to be modified.

Example: Road access and grizzly bear mortality

In the West Okanagan–Nicola Cumulative Effects demonstration project area, we are assessing the condition of the landbase to support grizzly bear, and understand how likely that condition is to achieve the objectives laid out in the North Cascades Grizzly Bear Recovery Plan.

In studies, increased grizzly bear mortality has been linked to road access.

The use of road density as an indicator assumes that grizzlies are more likely to encounter humans, and humans with guns, in areas with greater road density.

While these metrics are based on assumptions, we have evidence that suggests there is a greater likelihood that a grizzly bear will be killed as the density of roads increases. Therefore, we use road density information to help us understand the condition of the landbase, and how it has changed over time, relative to our objective to maintain or recover a viable population of grizzly bear.

There are number of assumptions and uncertainties inherent in using this road information. As new activities are proposed, field-based assessments would need to confirm if assumptions, such as the level of use or access constraints, are correct and adjust the risk accordingly.

Example: Road access and recreational opportunities

This work was done outside of our cumulative effects pilot area, but provides a good example of the complexity of road-related issues. Consider the roads and cutblocks around Andy Lake, just northwest of Kamloops. This lake is a premier walk-in fishing lake, part of a subset of lakes in the Timber Supply Area that were to be managed for walk-in only access through the Kamloops Land Resource Management Plan (LRMP) completed in 1996, and to which there are current legal objectives.

Because we don't know how many people are on these roads or if they are using these lakes, we can only assess the condition of this recreational objective at broad scales by measuring the density of roads within a 500 m perimeter around the lake (assuming walk-in status would be maintained if no, or few roads occur within this zone). In 1996 when the LRMP was completed, there were no roads within that 500 metre perimeter.

With extensive mountain pine beetle control and mountain pine beetle salvage starting in the late 1990s up to 2005, several new roads and cutblocks developed around the lake, including within that 500 metre perimeter. We investigated this lake and a number of others in 2007 and found that despite roads being de-activated by forest licensees, 4x4 vehicles and off-road vehicles such as ATVs were able to access the lake by these roads. They were creating trails through the cutblocks and actually parking on the shoreline.

Of 29 lakes assessed in the Kamloops, Merritt, and South Okanagan areas, 17 lakes were compromised in this way, suggesting that current efforts to maintain the social objective of a range of angling opportunities including walk-in only lakes was becoming difficult to achieve without additional intervention to restrict access.

In other areas of the province, however, road access can improve recreational opportunities by improving access to small fishing lakes. Increased angling effort can actually alter the population structure in a lake, reducing fish numbers and thereby increasing fish size, making those lakes even more attractive to anglers. So, it is important to keep in mind how we use these analyses against the objectives we are measuring.

Road sediment and water quality

One of the more direct effects of roads is generation and delivery of sediment into streams and the resulting impacts to water quality.

As before, we generally don't maintain updated information on road use status, and we don't have information on who uses roads, or on how often or how well roads are constructed and maintained. We also don't have reliable soil information at a provincial scale that can be used to inform us of erodible material that may have been used in roadbed construction. Therefore, to assess the condition of the landbase we must rely on assumptions, supported by literature of the potential for sediment to be generated and delivered into streams.

In the West Okanagan–Nicola Cumulative Effects Demonstration Project we are currently using a simple model of the potential for sediment to be generated and delivered by assessing a number of road-related indicators:

- the amount of road that is within 100 metres of a stream— includes crossings;
- roads that are on steep slopes—greater than 50%— that are directly coupled, or connected to, a stream; and,
- the amount of area harvested on gentle over steep terrain.

These metrics are used to provide a hazard rating of the potential for increased sediment to be generated and delivered to a stream based on the total amount of road in each of these indicators. We assume that more road length leads to a greater likelihood of sediment being delivered to streams. This model currently ignores important variables such as road construction, road maintenance, and roadbed material in an assessment of sediment generation because information is not consistently available for broad, GIS-based analyses. To overcome this data gap, we are currently working with provincial and regional soil experts to bring in spatial soil information and have also targeted Forest and Range Evaluation Program water quality effectiveness sampling in some of our watersheds. This uses field-based assessments of sediment input on the same segments of roads as identified in our model, to determine if the model can reliably project the likelihood of increased sediment input or make changes as appropriate.

Conclusions

So, part of our approach to addressing issues associated with cumulative effects is to make better information available to proponents, professionals, and government staff alike so that the multitude of landbase activities that affect that value can be considered in assessments and decision-making.

Through the development and testing of the Cumulative Effects Assessment Framework within the West Okanagan–Nicola Cumulative Effects Demonstration Project we've been able to build information that can be used to broadly assess the condition of values on the landbase. We've developed and tested these approaches and in general have been getting good support from knowledge experts and resource practitioners. Further review and refinement are required.

However, we know there are limitations to what we can do with this information, and recognize challenges in working with these datasets—particularly at this broad scale.

Informed resource management decisions will still largely rely on professional assessments completed on the ground. However a solid base of information shared by all will lead to better informed professionals, and better resource management.

Next steps

Specific ways that we see to improve include:

1. There is a need to link Values Screen information to ground-based monitoring, such as the Forest and Range Evaluation Program, to help validate and improve our certainty in these models. If the Values Screen information is used to help inform decisions upfront, then we also need results-based information through monitoring as part of an effective feedback loop.

2. We need to identify where the uncertainties and data gaps exist in our understanding of current condition of values. By explicitly building these models, which use existing information to interpret the condition of values, it forces us to state our assumptions and acknowledge uncertainty, thus deliberately exposes our weaknesses—which some people are reluctant to do. This is not necessarily a bad thing as it can help to direct research towards filling the data gaps.

Recommended reading

Krzyzanowski, J. and P. Lara Almuedo. 2010. Cumulative impacts of natural resource development on ecosystems and wildlife: An annotated bibliography for BC. FORREX Forum for Research and Extension, FORREX Series 26. http://forrex.org/sites/default/files/forrex_series/FS26.pdf

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17. Forest Practices Board presentation on road and bridge practices – What have we seen?

Co Presenters:

Chris Mosher, Director, Audits, Forest Practices Board, Victoria BC
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Garth Lord, Contract Auditor, Cascade Forest Engineering, Salmon Arm BC
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The Forest Practices Board (FPB) was established in 1995 with the implementation of the Forest Practices Code. The Board was continued under the *Forest and Range Practices Act* (FRPA) and the *Wildfire Act* (WA). The Board is comprised of seven part time members and a full time Chair, who along with professional staff, conduct audits and investigations and issue public reports about how well industry and government are meeting the intent of British Columbia's forest and range practices legislation. To date it has issued more than 400 reports. All of the Board's reports are available on our website: http://www.fpb.gov.bc.ca/

This presentation summarized Board observations with regard to road and bridge practices on British Columbia's Crown forestry and range lands during the past seven years of operation, bearing in mind that currently we only assess planning and practices under the FRPA and WA, as specified by our mandate.

Board staff often encounters practices on the land base, such as the construction of a road, which is authorized through other legislation, such as the *Land Act*. These practices are outside of the Board's current mandate, therefore cannot be assessed, as described in the 2010 Toba Montrose Creek Hydroelectric project complaint investigation:
http://www.fpb.gov.bc.ca/IRC175_Forest_Resources_and_the_Toba_Montrose_Creek_Hydroelectric_Project.htm?terms=toba

The mandate issue has been discussed internally by the Board for several years now and since the *Natural Resource Road Act* will be silent on the issue of independent oversight on resource roads, and given the recent integration of the resource ministries, it seems logical that the Board mandate would be expanded to allow Board auditors to assess all of the roads a licensee has constructed, not just those authorized under FRPA.

The FPB has published 149 audit reports to date, and from 2005 through 2011, we have conducted 59 compliance audits, involving 96 licensees and 17 BC Timber Sales districts. During that period, 24 audits had findings, including 37 audits where there was significant non-compliance, 22 areas requiring improvement, and 6 unsound practices.

During that timeframe, the population of activities audited included:

- 1,700 kilometres of road construction;
- 560 kilometres of road deactivation;
- 15,900 kilometres of road maintenance;
- 150 bridges constructed; and ,
- 1,480 bridges maintained.

We generally sample between 10 percent and 100 percent of the populations, depending on the size of the populations and the inherent risks.

Regarding road and bridge practices, FPB auditors generally focus on a few specific sections of the *Forest Planning and Practices Regulation* (FPPR) (http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/12_14_2004) such as:

- Section.72 – Roads and associated structures;
- Section75 – Structural defects;
- Section 77 – Retaining information;
- Section 79 – Road maintenance;
- Section 81 – Wilderness roads;
- Section 82 – Road deactivation; and as well,
- Some FPPR sections regarding natural drainage patterns and protecting fish and fish habitat.

We have found some aspects of road and bridge compliance to be quite straight forward, such as section 82 – if you deactivate a road, you need to barricade the road surface. If you don't, and you don't have a district manager exemption, you are in non-compliance. And section 75 – if you have a known structural defect on a bridge, you must correct, close, remove, or replace the bridge. If you use the bridge with a known structural defect, you are in non-compliance.

Other sections are not so straight forward. For example, section 72 and section 79(6) of FPPR both use the term "must ensure" in the legislation – but what does that mean?

72 – Roads and associated structures

> A person who constructs or maintains a road must ensure that the road and the bridges, culverts, fords and other structures associated with the road are structurally sound and safe for use by industrial users.

79 – Road maintenance

> (6) A person required to maintain a road must ensure all of the following:
>
> > (a) the structural integrity of the road prism and clearing width are protected;
> > (b) the drainage systems of the road are functional; and,
> > (c) the road can be used safely by industrial users.

Section 79(6) has been a real head scratcher around the Board office for quite some time. Various staff, contractors, Board members, and Ministry of Forests, Lands and Natural Resource Operations staff have landed on both sides of the fence on this issue.

A recent Board audit highlighted this issue:
http://www.fpb.gov.bc.ca/NEWS_RELEASE_ARC145_Audit_of_TFL54_on_South_Island_finds_issues.htm

In this audit, a TFL holder operating in a high risk coastal area (Clayoquot Sound) had not assessed many of their roads since taking over the licence four years prior. Although no slides had occurred to date, are they "ensuring" the roads are structurally sound and safe for industrial users? Is this a non-compliance? Is there a difference between good management and just good fortune?

Since this specific issue has not been defined elsewhere, the Board chair developed the following rationale:

> The legislation would not include the term "must ensure" if it did not intend there to be positive, deliberate action taken to achieve the results. For the Board, this means it is reasonable for an auditor to describe the absence of positive, deliberate action as non-compliance, whether or not there has been a failure to achieve a result.

> Therefore, when auditing compliance with section 79(6) of the *Forest Planning and Practices Regulation* (FPPR) the absence of any proactive management to ensure achievement of the required results may be considered non-compliant by the Board.

This issue also arose in a 2012 audit:
http://www.fpb.gov.bc.ca/ARC144_Amabilis_Contracting_NRFL_A79575_in_the_Cariboo-Chilcotin.htm?terms=amabilis

In this audit, there was a similar lack of active management but there were few forest values, therefore the finding was not considered significant, although it was still a non-compliance.

However, before a potential finding can be discussed, the specific road or bridge must be assessed in the field. The following pages show examples of road and bridge practices that the Board auditors have seen on various projects—both complaint and non-compliant.

Figure 1. *Compliant—An example of a well-constructed, stable road prism. Note the ditchlines installed even through rock.*

Figure 2. *Compliant—Road deactivation, showing a deactivated bridge crossing. Both approaches have been well armored to reduce the potential for erosion.*

Figure 3. *Compliant—Structure with sediment traps and check dams along ditchlines. This is the most effective method to capture and reduce sediment delivery to streams.*

Figure 4. *Compliant—Section of new road within a community watershed that is well capped to reduce the potential for sediment delivery.*

Figure 5. *Bridge located on a wilderness road and is accessible by the public. Compliant with FRPA but not a sound practice or safe for public use, despite being legal.*

Figure 6. *Not compliant—Road maintenance. Failure of a road prism. Road under permit but considered a wilderness road. Still used by the public. No warning signs and failure of the culvert caused introduction of sediment into an S4 stream.*

Figure 7. *Not compliant—Poor road construction. Failure of a 3 year old road prism. Note excessive organics in fill.*

Figure 8. *Not compliant—New bridge construction: not following plans. We recommended immediate removal and the licensee complied.*

Figure 9. *Not compliant—Bridge maintenance: cracked and broken stringers and guard log. Road was crossed with equipment.*

Figure 10. *Not compliant—Mismanaged water over a road system. Note erosion over the road prism and ditchline.*

Conclusion

In the seven years of audits between 2005 and 2011, involving 96 licensees and 17 BCTS programs, over 50% of all findings relate to roads and bridges!!

- 22 of the 37 significant non-compliances noted related to roads and bridges (59%). Includes not ensuring roads are structurally sound, not blocking deactivated roads, using unsound crossings, and poorly built roads and structures.
- 12 of the 22 areas requiring improvement (55%). Mostly dealing with road maintenance.
- 4 of the 6 unsound practices (67%). Mostly relating to not following the plan for road construction. Prescribed full bench end-haul, yet material was sidecast.

In general, the Board has found that the majority of roads and bridges are well constructed and maintained, but many aren't. We've also observed that there seems to be a trend towards reducing costs through cutting corners, evidenced by decreased overall maintenance work and using few or no culverts during road construction. The Board is not sure if this is due to the economy, or due to the number of players on the landbase, or due to the legislation—but there were more audits with significant findings in 2010 and 2011, than in the five previous years combined.

It is our hope that this trend will be reversed through better management of road and bridge practices in the future.

Recommended reading

B.C. Forest Practices Board. 2005. Managing landslide risk from forest practices in British Columbia. Special Investigation Report FPB/SIR/14. http://www.fpb.gov.bc.ca/SIR14_Managing_Landslide_Risk_from_Forest_Practices_in_BC.pdf

B.C. Forest Practices Board. 2009. Fish passage at stream crossings. Special Investigation Report FPB/SIR/25. http://www.fpb.gov.bc.ca/SIR25_Fish_Passage_at_Stream_Crossings.pdf

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18. Summary of closing comments

Al Gorley, Chair, Forest Practices Board, Victoria BC
al.gorley@gov.bc.ca

Congratulations to the organizers, presenters, and attendees for making this a high quality conference on an important subject.

What I heard

Rather than try to summarize all of the presentations I noted a few key messages (“Tweets”) that reflect some of the flavour:

- Good information is needed to inform government on how you would like to manage back-country roads.
- The choice is ours.
- The road layer is absolute garbage.
- Natural processes provide solutions to even the toughest restoration problems.
- Prevention and early control are the biggest bang for the buck.
- We have to take more of a landscape level approach.
- We need to be more strategic.
- BC fish deserve better.
- Tyranny of small decisions.
- 59% of all Forest Practices Board findings are related to roads and bridges.

What it tells me

The following points represent my interpretation of the combined presentations over the past day and a half:

- Roads are necessary but have risks and negative consequences that can be mitigated. Water is a particular concern.
- We’ve come a long way to develop tactics (practices) to do a better job but we still struggle with strategic solutions that we’ve know about for over 25 years.
- We need a better overall approach to developing landscapes (e.g., multi-value risk assessments and better spatial and temporal coordination). Perhaps we need to adopt an operating principle of “as little road as necessary to get the job done”.

- A lot of knowledge exists: there are best practices for construction, maintenance, monitoring and remediation. We need to apply and continue to build on best practices—learn from experiences and unintended consequences.
- We need to maintain the management system to inventory and track roads. For legacy roads we have to be smart about how to invest limited resources. Should we invest scarce resources in inventory if we don't intend to do anything with the information?
- Mitigation and remediation can be used where necessary to meet landscape objectives. It's expensive, should start early and be based on clear priorities.
- We need to do a better job of managing human behavior. Educate users—develop a culture to counter to some popular media images of motorized backcountry use. Enlist people on the ground (users).
- This is public land. We need to earn public confidence with reliable independent oversight and evaluation that applies to all activities on the landscape. This needs to be supported with consistent reporting and continuous improvement.

What now?

As individuals we should constantly encourage best practices.

Collectively we need to push for coordinated management and oversight with a long-term perspective. Without profile the resource roads issues will lose out to other public priorities.

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Posters

1. **Mitigating road impacts at the site level: Using the US Roads Analysis process to identify where to invest effort and money.** Patrick Daigle, RPF (Retired), Victoria
   p.daigle@telus.net

2. **East Kootenay Invasive Plant Council,** Marty Hafke, EKIPC Coordinator, Cranbrook
   coordinator@ekipc.com
   http://www.ekipc.com/

3. **Road densities across British Columbia,** Malcolm Gray, GeoBC, Ministry of Forests, Lands and Natural Resource Operations, Victoria BC
   malcolm.gray@gov.bc.ca

This GeoBC poster gave a visual impression of road density across the province, plus some qualifications on the currency of that view. This topic is related to one of the objectives of the *Natural Resource Road Act* initiative, which is to improve our inventory of resource roads. A complete resource road inventory would allow better and more consistent management of road impacts, particularly at the strategic or landscape level. Below is a clip from a previous (circa 2007) view of Provincial road densities.

4. **Suspended sediment contributions from a forest road in the Honna River watershed,** David A. Reid, University of British Columbia, Vancouver BC
   david.reid@geog.ubc.ca

Co-authors:
Marwan Hassan, Department of Geography, University of British Columbia, Vancouver, BC
William Floyd, Ministry of Forests, Lands and Natural Resource Operations, Nanaimo BC

The Honna River forms important salmon habitat and is the primary source of drinking water for the Village of Queen Charlotte on Haida Gwaii, British Columbia. There is concern that sediment from an unpaved forest road is contributing to poor water quality in the river. The focus of this research project is to quantify the amount of sediment entering the channel from the road and to determine its importance relative to other sediment sources at the reach scale. To address this issue, a reach sediment budget will be developed by measuring all components of input, storage, and output. Fine sediment will be measured with five turbidity probes, three in the channel and two on road ditch drainages. In-channel fine sediment storage will be determined through the sampling of bed material at 20 sites in the reach. Coarse sediment transport rates will be estimated through the use of 240 magnetic and 240 non-magnetic tracer stones positioned at the top and partway down the reach, and the storage of coarse material will be quantified from a series of cross sections combined with sediment dating through the use of dendrochronology. Sediment emanating from lateral channel erosion will be measured through the installation of bank erosion pins, and by measuring vegetation age along banks. In addition to the reach study, seven other turbidity and water-level recording sites will be used to conduct a basin-wide survey of forest road sediment sources in order to assess the significance of road-related sediment at the watershed scale. The outcomes of this research will be used to help manage and mitigate road-related sediment input to streams, potentially reducing the cost of drinking water treatment and improving stream habitat and overall water quality in a range of environments.

5. **Monitoring Canada's deforestation,** Andrew Dyk, Canadian Forest Service, Natural Resources Canada, Victoria BC
adyk@nrcan.gc.ca

Co-authors
Don Leckie, Sally Tinis, Stephanie Ortlepp, Canadian Forest Service, Natural Resources Canada.

Deforestation happens when humans clear forested areas permanently to use the land for another purpose, such as agriculture or urban development. Since 1990, approximately one million hectares of forest in Canada have been converted to other uses. Primary drivers of forest conversion include agricultural expansion, resource extraction, and hydroelectric development.

The Deforestation Monitoring Group at Natural Resources Canada tracks deforestation using Landsat and other satellites, aerial photos, Google Earth imagery, provincial records and expert judgement. They provide reliable information to policy makers, land managers, and the public on the quantity, trends, and driving forces of deforestation. The official estimates of Canada's deforestation appear in the annual

State of Canada's Forests report, provincial government summaries, and Canada's annual reporting on greenhouse gas emissions to the United Nations.

6. **DWB Consulting Services Ltd.,** display panel. Brian Aitken, Prince George, BC
baitken@dwbconsulting.ca
http://www.dwbconsulting.ca/index.php

7. **Hoskin Scientific display booth,** Grant Barr, Hoskin Scientific, Burnaby, BC
gbarr@hoskin.ca
http://www.hoskin.ca/

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Summary of comments from workshop evaluations

Of the 80 evaluation forms distributed to the participants, 35 were returned. Not all participants responded to every question.

1. How well did the workshop meet your expectations?

Exceeded (one participant added this category)
Fully met – 11 people
Met most – 22 people
Met only a few – nobody selected this category
Did not meet any – 1 (Participant said he thought the event would address backcountry access)

2. Please suggest two or three key things that you learned at this workshop. Are there things you will be doing differently in the future?

Provide more/better guidance to practitioners
Step up efforts to collaborate with other stakeholders
Work more closely with the team building the *Natural Resource Road Act.*

Learned new *Natural Resource Road Act* information
Learned about fish passage working group activities

The range of assessments being completed – within the province and south of the border
The opportunity for collaboration
The status of the *Natural Resource Road Act*

Provincial statistics for FREP results
Deforestation calculation techniques

Will follow-up and participate in reviews of *Natural Resource Road Act*
Great seeing emphasis on culverts – will field review stream crossings and speak with planners and Ops re info presented
Emphasis on "rough and loose" in dealing with restoration and drainage
Question government and CBT re "mitigation" on wildlife impacts.

A few interesting points from Peter Jordan's talk; Marlene Machmer's talk was also informative.

Resource roads interact with many disciplines
Networking opportunities were great, to see who does what

Greater appreciation of the effects of roads on wildlife species
Greater appreciation of the issues balancing the reclamation of disturbed sites with invasive species management and objectives

Great bioengineering recommendations
Appreciated gaining information and access to PSCIS and new guidebook

Stream crossing practices are better but still not where they need to be

There is tons of work to be done in order to make resource roads acceptable
There are some great tools being designed to start inventories of roads, culverts, fish use, etc.
Most definitely taking some of the stuff that I learned to the contractors I work with.

Having been away from BC for a time it was informative to have an update of current discussion and knowledge.
Alternative approaches, problem solving
Good to link the names to topics and focus.

Many of the same issues/problems identified 20–30 years ago still exist….
Sometimes worse now than when they were identified. We seem to manage risk with no long range plan and no funding.

Road surfaces are still a major contributor of sediment to streams.
With all the money spent since 1995 on stream classification, the database is still in poor shape. Where did this information go.
Will work on grading issues to improve the sediment delivery.

Will be looking at fish passage more carefully
Will pay more attention to noxious weeds
Will be looking at seed mixes and where we seed.

Constructing wetlands
Recontouring roads – more effective than if abandoned.
Resource roads, road fills, road diversions play a key role in landslides
Culverts are affecting fish passage.

Best management practices for amphibians at road crossings
Status of forest management practices and impacts on fish bearing streams

- Potential for road construction methods to reduce likelihood of sediment reaching streams (example of swales)
- Design options for channelling amphibian and reptiles when crossing roads during construction works.

We are seeing the same issues that were identified decades ago.
Need more action, compliance, and enforcement of regulations.
Need updated regulations.

Exposed to a number of resources developed by government agencies useful for resource managers, e.g., road crossing guidebook and GIS tools.

Impact of roads on species at risk and other wildlife.
Amount of culverts and roads in BC which are causing problems.
Lack of resources in BC to address problem culverts and roads *vs* in the US.

More research going on that impact forest road planning design, construction, maintenance, and deactivation.
More communication between ministries.
Will try to communicate more in the future. Likely not going to happen, no time for this.

Received more details on *Natural Resource Road Act*.
Magnitude of invasive weed problems.
Active *vs* passive road construction.

Will try to partner with individuals and organizations doing assessments, e.g., on fish streams to include other SAR. There are different assessments being done.
Sheer numbers and density of resource roads in BC. Consider how my paved road network could expand to include resource roads.
Discuss overlapping issues – e.g., a package of dealing with water: landslides, site restoration, water quality, fish, amphibians.

Rough and lumpy concept, use of grass seed in bioengineering,
Sediment delivery to streams

Good to see summations of efforts regarding monitoring, state of current conditions, and research.

I learned how the environmental impacts of management are handled and regulated in BC.
Saw specific examples of road impacts on water
Great overview of fish passage site reviews

Grass seeding not recommended for ecological restoration
Recontouring and excavating of forestry roads will be much more effective for ecological restoration than abandonment.

I really enjoyed Rebecca Lloyd's talk on reclamation, but probably learned the most from Don Gosnell's presentation regarding legislation in BC.

Impacts of roads and sediment generation – consider this in access management.
Planned access management component of NRRA – very positive action to allow resource managers to deal with access issues.

Exposed to new fields of work and study I was not familiar with.

Limited new information was presented. Most presentations summarized work that had already been published. Presentations by Marlene Machmer and Elke Wind were exceptions.

How far silt can travel to get into a fish-bearing stream.
The correct way to cross fish bearing streams.
In the future I will be evaluating activity near streams more critically.

3. Do you have any other comments about the workshop?

Great workshop, terrific engagement!
Unfortunate that more industry and government practitioners weren't here.
Underscores the need to communicate and reach out to those who couldn't attend in person.

Good variety of presentations and topics.

Engage more industry otherwise we are preaching to the choir.
Engage more Alberta people – both as participants and speakers.

Oil and gas- want more info
Address more of what happens in semi-arid areas especially for construction and reclamation.

Nicely balanced topics
Great to see punctuality, thanks!

Good mix of presentations
Could have made use of extensive US work on road impacts on wildlife
Appreciated the wildlife impact overview by Patrick and research (Marlene) but could have had more in this vein.

Well run, on time, great nutrition
Perfect size of group

Very important to continue these workshops.
Need to expand target audience to include road foremen and machine operators.
Focus on stream crossings and drainage structures.

Great format, presentations were well done and presenters fed off each other and made a very knowledgeable group for discussion.

Liked size (venue and attendance), short presentations, on time.

Good room, good service.
Large round tables would be better for seating
Good organization, good speakers.

Most talks were rushed, maybe allow more time for each speaker.

Hold the conference in a different venue. Poor lunch.

Liked the diversity of discussions, people from many sectors were represented
Was hoping for more posters.
Should have been a group dinner or ice-breaker.

Could allow for more panels to encourage more discussion.

Conference was over-represented by regulators and government led research initiatives.

This particular topic would benefit form a contribution form practitioners, proponents, licensees, road builders, etc.
It would be good to highlight the aspects that enable and hinder good road building and maintenance.

Very informative.

The food wasn't great.
Some audiovisual and microphone issues.

Liked the accurate agenda, it gave what was promised.

As an attendee from the wildlife recreation sector, certain speaker topics were too detailed and scientific.

Well organized and run, nice format, like the 1.5 days format.

Too many acronyms were used.

Would have liked to see more from industry perspective. Felt it was a little skewed by government content.

Well done, good range of issues to show far-reaching implications of road issues.

Wants lapel microphone instead of hand-held. Wants microphone for audience questions. (3 people with similar comments)

The mixing time with posters and beer was very helpful to get to talk to people informally, great idea.

Did not give as much technical information on how to solve problems as I'd hoped.

Excellent job but lunch was insufficient.

Need more info on impact of access on wildlife habitat. Effectiveness reduction and displacement from harassment.
Good mix of speakers and good quality of presentations.
Would be better to have time for more discussion on issues, panel and/or general discussion rather than just questions after individual talks.

Good job

Develop a mandatory standard for presentations.
Consistently small photos, font size, text boxes. Too much info per slide.

I found it very educational. Valuable insight into environmental impacts. This will help with my job as a geologist.

Well run, on time, you did not try to jam in too many speakers.

Reponses for the following two questions are combined, below.

4. **The presentations at this workshop were the result of a Call for Papers. If we hold a sequel to this event, what topics would you like to see included?**
5. **If we host a conference on landscape-level road management, what topics would be important to you?**

Insight into permitting aspects.

Documenting records of mapping roads and road types, stream passage etc.
Numbers of roads that have been abandoned, etc.

Development of coordinated access management planning (CAMP) as a tool for public and resource agencies t use in addressing impacts.

Techniques for managing access, more information on remediation and reclamation techniques.
Involve land use planners, tenure holders, and really emphasize long-term planning and communication or lack thereof, which I just learned is called “the tyranny of small decisions”.

How to ensure that road deactivation is more than just removal of stream crossing structures but actual ecological restoration (recontouring and forestation) of roads.

Climate change impacts on managed watersheds.
Field trip to look at a site, allows more person-to-person discussion.

Reducing the amount of roads (avoidance) by planning is an important function that government used to perform through review of FDPs. Road planning is critical to reduce future problems.

Road date is poor and needs to be addressed with licensees keeping better records and making data available to government.
Public access and use of "wilderness" roads needs to be better addressed. If they are to remain open, there needs to be better maintenance and monitoring. The public paid for these roads and rightly expects benefits.

Road building techniques and maintenance techniques – how to improve on them.

More wildlife talks *vs.* fish passage talks. Effects of roads can expand into upland areas.
Any studies that tried to model or predict a problem?
What about road crossing areas, e.g., migration?
Have you thought about using webinar/internet formats?

Wants talks on road density impacts on ungulates and large carnivores
Public involvement in access management strategies.
Conference dedicated to the *Natural Resource Road Act*, open to public, with question and answer segments.

Better management of roads – CAMP and its future in directing GIS work.

Inventory of roads – state of our inventory and GIS access to it

Impacts of roads on habitat suitability
Present density of roads by category of use
What are acceptable densities

Identify key projects or industries that can contribute to discussion. Not just a call for papers.
Landscape level is a great topic. Resist the temptation to focus on papers that are overly complex and will not be realistically considered for implementation.

Wildlife connectivity
Looking forward to landscape level event.
Do not limit to resource roads, include other transportation such as highways, rail, mining.

Are roads in oil and gas sector being reclaimed
What are lessons learned by engineers and construction workers who build the access roads.

What are deactivation practices around streams
Is the NNRA going to improve access planning and maintenance, how is it going to make the road user more accountable?

Road access, prescription, implementation and monitoring, e.g., FRBC tech circulars for deactivation
Access management, risk management, assessment
What are healthy ecosystems

Would like to see some current project and construction specs and how these are different to the past.
Wants to hear from a similar group of presenters from across the US border. What has worked and not worked in another country.

What are some innovative construction and maintenance practices to provide fish passage and habitat integrity.
How to translate higher level plan objectives to access management.
How to resolve land management conflicts – a tool kit for everyone involved.

A way to encourage information sharing.

Information about new iPad tools – such as the new "Consolidated Road Atlas"?

More on road impacts to wildlife – movement, habitat use, predation
How to reduce number of roads and road footprints in planning

Hot spots for issues
Cumulative effects and stressors on landscapes
Followup on presentations and statistics presented at this workshop.

What are licensee perspectives on road management and control of sediment erosion and water management?

Restoration after removing stream crossing structures
Wants multi-disciplinary perspectives from various industries and tenures on land use and roads.
Address cumulative effects assessment and management.

6. Do you have suggestions for other events or course that Columbia Mountains Institute can host?

Each fall there is a "Minerals South" conference held in Nelson or East Kootenay. Some of these presentations would be valuable at these conferences.

Run the soils refresher course again.
Wants an Intro to GIS course.

Road maintenance and deactivation workshop.

Habitat requirements of species at risk in the Kootenays and how to meet them.

With shrinking government resources we need to discuss the issue of Professional Reliance.

Wildlife connectivity across highways. Virtually ignored in BC.

Would be interested in a course on IPPs or impacts related to micro-power construction.

Landscape level plans for maintaining wildlife habitat and connectivity.
Site level management practices to enhance habitat suitability.

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